Volume LXXIII Number 2

# THE BOTANICAL GAZETTE

Editor: JOHN M. COULTER

FEBRUARY 1922

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# THE BOTANICAL GAZETTE

A MONTHLY JOURNAL EMBRACING ALL DEPARTMENTS OF BOTANICAL SCIENCE

EDITED BY

JOHN M. COULTER

With the assistance of other members of the botanical staff of the University of Chicago

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# PLANT GENETICS

*By*

**JOHN M. COULTER**

Head of the Department of Botany in the University of Chicago

*and*

**MERLE C. COULTER**

Instructor in Plant Genetics in the University of Chicago

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THE

BOTANICAL GAZETTE

*February 1922*

# SULPHUR AS A FACTOR IN SOIL FERTILITY

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JOHN WOODARD

## Introduction

Although sulphur was recognized as an essential element in plant nutrition as early as the middle of the nineteenth century, the use of sulphur and sulphur compounds as fertilizers has never become general. Analyses for sulphur in soils have generally been low, yet when compared with the sulphur in the ash of plants, the amount present in the soil seemed sufficient for all the needs of the crop. The use of gypsum as a fertilizer, however, was quite extensive for a time, following the discovery of its beneficial effect on plants. BROWNE (13) credits this discovery to a clergyman in Germany in 1768. From there it spread to France and Great Britain, and was brought to the United States by BENJAMIN FRANKLIN, who used it on his farm near Philadelphia. For a time gypsum was extensively used as a fertilizer both in Europe and the United States and gave remarkable results. GRIFFITHS (25) reports experiments by SCHUBERT in Germany, and CROCKER (15) refers to the experiments of Judge PETERS, JOHN BINNS, and EDMUND RUFFIN in the United States. All these men obtained remarkable results with gypsum on legumes.

The use of gypsum alone, however, soon failed to increase crop yields, and investigators seeking for an explanation came to the conclusion that the gypsum acts chemically on the phosphorus or potassium compounds in the soil and liberates either phosphorus or

potassium or both. This view is presented by GRIFFITHS (25), VOORHEES (72), and HOPKINS (32). BROWNE (13) and BRUCKNER (14) consider the beneficial effect of gypsum due, in part at least, to the nutrient effect of the sulphur; while VENDELMANS (70) and HILGARD (31) mention its beneficial effects, particularly on the legumes, without giving any explanation.

In most fertilizer experiments sulphur has been added, together with phosphorus, in acid phosphate or basic slag, or with the potassium in potassium sulphate or kainit. When beneficial results have been obtained, the investigators have invariably ignored the possible effects of the sulphur. This may lead to erroneous conclusions, as was pointed out by LIEBIG (37) in 1855. He said that the sulphur or the calcium in the acid phosphate, or both, might have had a beneficial effect on the turnips in the Rothamsted experiments, as well as the phosphorus.

HOPKINS, MOSIER, PETTIT, and READHIMER (33) found that kainit increased the yields of corn, wheat, and oats on the waste hill land of Johnson County, Illinois, when used with bonemeal, ground limestone, and crop residues, over similarly treated plots without kainit. On the plots receiving no kainit, as well as on those receiving the kainit, cowpeas were grown once every three years and turned under as part of the crop residues. STEWART (66) compared potassium chloride and potassium sulphate as fertilizers for apple orchards in Pennsylvania. He found no appreciable difference in the effect of these salts. SMITH (65) found a greater yield of oat straw for potassium sulphate than potassium chloride in pots containing Hagerstown silt loam.

BROOKS (8) compared the effects of potassium sulphate and potassium chloride on alfalfa in field experiments at the Massachusetts Agricultural Experiment Station. Both plots received 600 pounds of bonemeal per annum, and both received 2 tons per acre of hydrated lime before planting the alfalfa. Both Grimm alfalfa and common alfalfa were used. Potassium sulphate gave increased yields of 0.50 tons of Grimm alfalfa and 0.75 tons of common alfalfa over potassium chloride. In every case the alfalfa on the plots receiving potassium sulphate was a darker green than on the plots receiving potassium chloride. The same difference in color

was reported for the same treatment on other crops. BROOKS (9) also made a comparison of different phosphate fertilizers. He found that acid phosphate and dissolved boneblack, which contain sulphur, gave greater increases in crop yields than raw bonemeal and rock phosphate, which contain little or no sulphur. A more rapid early growth of both tops and roots and earlier maturity were observed on the plots receiving the dissolved boneblack and acid phosphate than on the plots receiving raw bonemeal and rock phosphate.

The use of flowers of sulphur as a fertilizer was observed to have an influence aside from its effect in destroying the fungi which cause plant diseases. MARES (50) noticed a much greater vigor in vines that had been sulphured than in those which had not. He found that the sulphur was oxidized to sulphuric acid in the soil, and he thought that the sulphuric acid acted on the insoluble compounds containing potassium and made the potassium soluble. DEMOLON (16) found that heating the soil prevented the oxidation, and so he concluded that oxidation was caused by microorganisms. PFEIFFER and BLANCK (56) obtained no increased yields of oats for the use of flowers of sulphur in field experiments. FEILITZEN (21) in Europe, and SHERBAKOFF (64) in the United States both obtained increased yields of potatoes from the use of flowers of sulphur.

BOULLANGER and DUGARDIN (3) found flowers of sulphur increased ammonification but decreased nitrification. The harmful effect on the nitrifying bacteria was probably due to the acidity, as LINT (38) found that the oxidation of sulphur in the soil increased the acidity very much. FRED and HART (23) report an increase in ammonification from the use of gypsum in peptone solutions, and WARINGTON (73) obtained an increase in nitrification when gypsum was applied to solutions of urea. GREAVES, CARTER, and GOLDTHORPE (24) studied the influence of calcium sulphate on production of nitrates and found it caused a great increase in all concentrations used. The increase was very high for the higher concentrations of calcium sulphate.

BRIOUX and GUERBET (7) found that flowers of sulphur increased availability of calcium and potassium in both calcareous

and noncalcareous soils, but had no effect on phosphorus. LIPMAN and MCLEAN (42) found that composting rock phosphate with sulphur increased the solubility of phosphorus. MCLEAN (48) found an increase of solubility of phosphorus in the sulphur-rock phosphate compost when compost was inoculated. The presence of soluble phosphates and sulphates did not inhibit the action. LIPMAN, MCLEAN, and LINT (43) found a great increase in acidity in the sulphur-floats mixture. LIPMAN and JOFFE (41) found no increased availability in phosphorus when acidity was increased by the addition of sulphuric acid. ELLETT and HARRIS (20) found greater availability of phosphorus in a manure-soil-floats-sulphur compost than in a soil-floats-sulphur compost. AMES and RICHMOND (2) found no increased availability of phosphorus in a compost to which calcium carbonate had been added. Acid conditions are necessary for the solution of the phosphorus. BROWN and GWINN (10) found an increased solubility of phosphorus in soil treated with sulphur as well as in composts. BROWN and WARNER (12) found no increased solubility of phosphorus in a manure-floats compost, but a great increase when flowers of sulphur were added to the compost.

The use of gypsum as a preservative of the nitrogen in manure has been investigated by HEINRICH (30), VIVIEN (71), NOLTE (53), and by AMES and RICHMOND (1). All these investigators report a saving of nitrogen from the use of gypsum on the manure.

Investigations on the effect of flowers of sulphur on the availability of potassium in greensands were conducted by MCCALL and SMITH (45). They found an increase in the availability of potassium in composts of sulphur, greensands, and manure, but no increase in availability of potassium in composts of sulphur, greensands, and soil.

Reports of investigators who studied the influence of gypsum on the availability of potassium do not agree. MCCOOL and MILLAR (46) found calcium sulphate applied to soil lowered the freezing point of the soil. No report was given as to the character of the compounds that lowered the freezing point. BRADLEY (4) found an increase in solubility of potassium but not of phosphorus in Oregon soils. BRIGGS and BREZEALE (6) found a decrease in

solubility of potassium in California soils when gypsum was added, and the solubility of potassium decreased as the amount of gypsum used was increased. BREZEALE and BRIGGS (5) grew wheat in water cultures, using extracts from orthoclase minerals with and without gypsum. The gypsum did not increase the availability of the potassium to the wheat. MORSE and CURRY (52) treated feldspars with gypsum for ten weeks in water, filtered off the solution and analyzed for potassium. Only slightly more potassium was found than when no gypsum was used. MCMILLAR (49) treated five different soils with gypsum for three months and analyzed for soluble potassium. Gypsum was used at the rate of ten tons per acre and resulted in an increase in soluble potassium in every case. TRESSLER (69) found an increase in soluble potassium in some soils, but no increase in others when treated with gypsum. LIPMAN and GERICKE (39) obtained an increase of available potassium in greenhouse soil, a slight increase in adobe soil, and no increase in sand. FRAPS (22) grew plants in pots of soil treated with gypsum and analyzed the plants for potassium. He found no increase in potassium in plants grown on the gypsum-treated soil above that on the soil without gypsum. He reports no analyses of the soils used, however, so it is not known whether these soils were deficient in potassium or not. If the soil has sufficient potassium in an available form to supply all the plants' needs, there would not likely be any increased absorption even if the soil treatment dissolved some of the insoluble potassium compounds in the soil. On the other hand, in a soil deficient in potassium and sulphur, the application of gypsum or any other fertilizer containing sulphur would stimulate the growth of roots, and the increased size of the root system would make it possible for the plant to absorb more potassium. This increased absorption would take place regardless of any possible effects on the solubility of the potassium compounds in the soil.

The experiments of MCMILLAR (49), TRESSLER (69), and LIPMAN (39) indicate a greater solubility of potassium in some soils when treated with gypsum, but other soils show no effect, while BRIGGS and BREZEALE (6) report a decrease in solubility when gypsum was used. It seems, therefore, that the beneficial

effects of gypsum can hardly be ascribed to its effect on the solubility of the potassium in the soil. It seems more likely that the soils that respond to the use of gypsum are deficient in some element that is supplied by the gypsum.

Recent studies of methods for the analysis of organic material for sulphur have shown that all the sulphur is not recovered in the ash when organic material is burned. HART and PETERSON (**27, 28**) found one hundred times as much $SO_3$ in the rice grain as in the ash of that grain, and forty times as much in the corn grain. Similar results were obtained with other grains, but the ratios were less in some cases. Onions, potatoes, crucifers, and legumes use large quantities of sulphur. Alfalfa removes twice as much sulphur as phosphorus from the soil. PETERSON (**55**) studied the sulphur compounds in plants and found proteins, volatile compounds, mustard oils, and sulphates. In ashing the plant material the sulphates remain, but at best part of the sulphur in other compounds is lost. Most soils are low in sulphur, which is present in the soil in the form of sulphates and organic matter. Sulphates are all soluble, and, like nitrates, they are not adsorbed to any great extent, and therefore are quickly leached out of the soil in the humid regions. The organic sulphur is insoluble but is readily oxidized to sulphates, so that it is gradually being lost unless taken up by the plant. LYON and BIZZELL (**44**) in their lysimeter studies at Cornell found that the loss of sulphur in the drainage from uncropped lysimeters was as great as the loss in drainage and in the crops from cropped soil. The oxidation of organic sulphur to sulphates seemed to continue at the same rate in cropped and uncropped soil, and that not taken up by plants was lost in the drainage.

Cultivation stimulates oxidation and consequently the loss of sulphur. SWANSON and MILLER (**68**) report a loss of 38.53 per cent of sulphur from the surface and 41.56 per cent from the subsoil of Kansas soils due to cropping. The surface soil of virgin land had 0.044 per cent sulphur, while adjoining cropped land had 0.027 per cent. The sulphur content of the subsoil was 0.062 per cent in the virgin land and 0.036 per cent in the cropped land. On the other hand, phosphorus was practically the same in the

cropped as in the virgin land in both surface and subsoil. The cultivated soils had been cropped for thirty to forty years.

LYON and BIZZELL (**44**) found an increased loss of sulphur in the drainage when burnt lime was used, while MACINTIRE, WILLIS, and HOLDING (**47**) found the loss greater for calcium carbonate than for calcium oxide. It seems the carbonate favors bacterial action much more than the oxide.

ROBINSON (**59, 60**) analyzed a large number of soil samples from different parts of the United States for sulphur and phosphorus. Most of them were low, some extremely low, in both phosphorus and sulphur. Many of the samples were much lower in sulphur than phosphorus. BROWN and KELLOGG (**11**) analyzed samples of Iowa soils and found the sulphur content varied from 719 to 938 pounds per acre in the surface soil, while the phosphorus content varied from 1289 to 1538 pounds per acre. SHEDD (**62**) analyzed samples of Kentucky soils and found the sulphur content in the surface soil varied from 213 to 1080 pounds per acre in virgin soil, and from 180 to 560 pounds per acre in cultivated soils. The phosphorus content in the surface soil ranged from 320 to 5860 pounds in virgin soil, and from 320 to 7240 pounds in cultivated soil.

Some sulphur is brought down from the air in rain water. The amount is probably greater during periods of heavy rainfall than when the precipitation is slight. Near cities, where a large amount of coal is burned, the amount is probably much greater than in country districts far from cities and railroads. The data, however, are too meager to form any definite conclusions. HALL (**26**) reports sulphur analyses of rain water at Rothamsted from 1881 to 1887 which give an annual average of seven pounds of sulphur in the rain water per acre per year. Analyses by HART and PETERSON (**27**) at the University of Wisconsin for part of a year led them to the conclusion that the amount in one year would be approximately the same as found at Rothamsted. STEWART (**67**) analyzed rain water at the University of Illinois and obtained as a seven-year average 45.1 pounds of sulphur per annum. All of these analyses are of rain water collected near cities. The water in the rain gauges is likely to be contaminated by dust and soot and by the droppings of birds which roost on the rain gauges.

LAWES and GILBERT (**36**) found, in their fertilizer experiments with red clover, that "the produce was considerably increased by the application of gypsum, and still more so by that of the sulphates of potash, soda, and magnesia, and superphosphate of lime." In four years the increased yield from the use of gypsum was 3.5 tons of dry hay, or an average of 0.9 ton per acre per year.

HUNT (**35**), at the Pennsylvania Agricultural Experiment Station, used gypsum in a rotation of corn, oats, wheat, and hay (timothy and clover). Gypsum was applied at the rate of 320 pounds per acre per rotation in two applications, 160 pounds to the corn and 160 pounds to the wheat. No other fertilizers were used, and no increases in yields were obtained from the use of gypsum. These experiments would be more valuable if the gypsum had been applied to the clover and other fertilizers had been used to remove the possibility of another limiting factor.

MILLER (**51**) grew clover in pots containing Oregon soils. Applications of sulphur were made in the form of flowers of sulphur, sodium sulphate, and gypsum. Gypsum and sodium sulphate gave increased yields, but the flowers of sulphur had little effect.

SCHREINER (**61**) studied the effect of different salts on oxidation in soil extracts in which wheat seedlings were grown. He reports increased oxidation from the use of calcium sulphate, potassium sulphate, and sodium sulphate.

DYMOND, HUGHES, and JUPE (**18**) compared the effect of ammonium sulphate and ammonium chloride on cabbages grown on non-calcareous soil. Greater yields were obtained with the ammonium sulphate than with the ammonium chloride. In their experiments with clover they obtained a 20 per cent increase in hay from the use of gypsum. In pastures they observed that legumes predominated where sulphates were applied, and grasses where no sulphates were used. Gypsum increased the yields of red clover, maize, and vetch in sand cultures, and of vetch in soil cultures. All the pots received applications of calcium and magnesium carbonates.

LIPMAN and GERICKE (**40**) compared the effects of different nitrogenous fertilizers on barley grown on Oakley's vitro sand, and found the greatest increase with ammonium sulphate. When

sulphur containing substances were added to the non-sulphur containing nitrogenous fertilizers, they produced yields equal to those from ammonium sulphate.

SHEDD (**63**) grew soy beans, oats, alfalfa, and wheat in pots containing Kentucky soils. Eight different soils were used, and flowers of sulphur added at the rate of 100 and 200 pounds per acre. Both controls and sulphur treated pots received tricalcium phosphate, potassium nitrate, and calcium carbonate. There were some increases but also some decreases.

EATON (**19**) grew sweet corn in pots containing sand. He compared the effect of gypsum, flowers of sulphur, and sodium sulphate. The controls as well as the different sulphur treatments were watered with a nutrient solution which contained no sulphur. Gypsum increased the yield, while flowers of sulphur and sodium sulphate gave increases for the smaller applications and decreases for the larger applications.

DULEY (**17**) reported a darker green in sweet clover and corn when fertilized with gypsum or sulphur. More nodules were also produced on the roots.

PITZ (**57**) grew clover in agar-agar containing dipotassium phosphate with and without calcium sulphate. Greater length of roots was obtained with the calcium sulphate. Clover was also grown in Miami silt loam with and without calcium sulphate. The calcium sulphate increased the root length.

HART and TOTTINGHAM (**29**) found a decided increase in development of beans, red clover, and peas when fertilized with either calcium sulphate or sodium sulphate. In beans and peas the increase was in the seed, in clover it was in the hay and roots. Sulphates increased the yields of both tops and roots in radishes. The yield of rape tops was increased by both calcium and sodium sulphates. Barley was not affected by the sulphates, and oats to only a slight extent.

OLSON (**54**) conducted field experiments with alfalfa at the Washington Agricultural Experiment Station and obtained increased yields from the use of acid phosphate and gypsum, but not from other forms of phosphorus. Two hundred pounds of gypsum per acre increased the yields of alfalfa from 100 to 500 per cent.

REIMER and TARTAR (**58**) conducted field experiments on several Oregon soils. Superphosphate, flowers of sulphur, rock phosphate, potassium chloride, potassium sulphate, iron sulphate, gypsum, monocalcium phosphate, sodium nitrate, ammonium sulphate, magnesium sulphate, sodium sulphate, iron pyrites, quick lime, and ground limestone were used as fertilizers. In almost every case enormous increases in yields (from two to ten times as much as the checks) were obtained for all the fertilizers containing sulphur, and no increase or only a small increase for the fertilizers which contained no sulphur. Acid phosphate was compared with gypsum and rock phosphate and with rock phosphate and flowers of sulphur. The yield on the plot receiving rock phosphate and gypsum was considerably greater, and that from the plot receiving rock phosphate and flowers of sulphur slightly greater, than the yield from the acid phosphate treated plot. The alfalfa on all the plots receiving sulphur in any form was a darker green than on the plots which received no sulphur.

Chemical analyses of soil samples from these experimental fields were made. The sulphur content varied from 0.015 to 0.038 per cent in the surface soil, and from 0.014 to 0.030 per cent in the subsoil. The phosphorus content varied from 0.048 to 0.076 per cent in the surface, and from 0.066 to 0.085 per cent in the subsoil. All were high in calcium, magnesium, and potassium.

## Investigation

The analyses made by ROBINSON (**59, 60**) show wide variation in the sulphur content of different soil types. His investigations, although extensive, have included only a part of the numerous soil types found in the United States, so that other soil types should be analyzed to discover their sulphur as well as their phosphorus content. It is also necessary to conduct field experiments on the different soils, as analytical data alone are not sufficient evidence on which to base fertilizer practice. This investigation includes soil analyses and field experiments. Soil samples from Indiana, Kentucky, Michigan, Ohio, and Wisconsin were analyzed for phosphorus, sulphur, and volatile matter (loss on ignition). Field

experiments were conducted in Indiana and Kentucky on the fields from which the soil samples were taken.

## Soil analysis

Methods of sampling.—The soil samples from Michigan and Ohio (nos. 1–9) were taken by Dr. William Crocker and those from Wisconsin (nos. 10–11) by Mr. E. H. Hall. The samples were taken in the usual way by means of a soil auger. The samples from Indiana and Kentucky were taken when the soil was very wet, and as only the surface soil was sampled, it was believed that more accurate sampling could be done by using a spade or shovel. Some soil was removed to a depth of seven inches, leaving one side of the hole vertical, then a thin slice of soil was cut with the spade to the full depth of seven inches. A narrow strip of this extending from top to bottom was removed for the sample. Three or four such samples from different parts of the field were taken and mixed to form a composite sample. The samples from Indiana were taken by John Woodard, except no. 18, which was taken by Mr. V. G. Mann, and those from Kentucky by John Woodard, except nos. 32–34, which were taken by Mr. J. C. Gentry. All the soil samples were air dried, sifted through a 2 mm. sieve, and thoroughly mixed.

Analytical methods.—Phosphorus was determined according to the official magnesium nitrate method of the Official Agricultural Chemists. A blank determination was run to determine the possible presence of phosphorus in the chemicals, but no phosphorus was found.

Sulphur was determined by a modification of the methods of Shedd and of Brown and Kellogg. In preliminary work it was found that higher results were obtained when the iron and aluminum were removed. In soils low in sulphur the barium sulphate precipitated very slowly, so, at the suggestion of Dr. Frederick Koch,[1] 10 cc. of approximately N/10 $H_2SO_4$ was added immediately before heating the solution and adding the barium chloride. This sulphuric acid was measured in a burette, and exactly the

[1] Unpublished work of Dr. Frederick Koch.

same quantity of the same acid was added to the blank determination, so that subtracting the blank subtracted the sulphur added in the sulphuric acid as well as that present in the reagents. In every case the 10 cc. was measured between the 10 and 20 marks on the burette. According to KOCH, barium sulphate does not precipitate readily when the concentration of the $SO_4$ ion is low. The addition of the sulphuric acid is then necessary to bring the concentration of the $SO_4$ ion up to the point where precipitation takes place readily. The method as finally adopted is as follows: The equivalent of 10 gm. of oven dry soil was weighed into a nickel crucible, moistened with a few drops of distilled water, and part of a weighed 20 gm. of sodium peroxide stirred in a little at a time with a nickel rod. (If the moisture was just right, reaction took place immediately without the application of heat, and the charge was fairly dry by the time most of the sodium peroxide had been stirred in. If too little water had been added, it was necessary to heat with an alcohol lamp to start the reaction. If too much water was added, it was necessary to heat with the alcohol lamp to bring to the desired degree of dryness before adding the last of the sodium peroxide.) After the charge was fairly dry, the rest of the sodium peroxide was placed over the charge, the crucible covered, and heated over a bunsen burner, raising the temperature gradually to a fairly high temperature which was maintained for an hour. After cooling, the fused mass was removed with hot distilled water to a 600 cc. beaker, neutralized with concentrated HCl, and then 10 cc. additional concentrated HCl added. The beaker was then heated for five or six hours on the steam bath with occasional stirring. It was then transferred to a 500 cc. flask, covered, and made up to the mark. The solution was shaken frequently for several hours and the 250 cc. filtered off. The 250 cc. of filtrate was transferred to a 600 cc. beaker, heated on the steam bath, and the iron, aluminium, and silica precipitated with ammonium hydroxide, allowed to stand a few minutes, and then filtered into a one liter beaker. The precipitate was washed with hot distilled water until the combined filtrate and washings had a volume of approximately 600 cc. Exactly 10 cc. of approximately N/10 $H_2SO_4$ was then added, heated to boiling, and 10 cc.

of hot 10 per cent $BaCl_2$ solution added a drop at a time from a pipette. The solution was boiled for ten minutes, placed on the steam bath for two or three hours, and then removed and allowed to stand over night. The barium sulphate precipitate was then filtered off, washed with cold distilled water, transferred to a weighed porcelain crucible, ignited to a dull red in a muffle furnace, cooled in a desiccator, and weighed. Blanks were determined using the same reagents and adding the same quality of the same sulphuric acid that was used in the determination.

The loss on ignition was determined on samples which had been used for determining moisture. The moisture was determined by heating 10 gm. of air dry soil in the oven for five or six hours. Part of the samples were heated to 100° C. in an ordinary oven and part of them to 35° C. in a vacuum oven. After weighing for the moisture determination, the sample was placed in the muffle furnace, heated to a dull red for an hour, cooled in a desiccator, and weighed. The loss on ignition was calculated as percentage of oven dry soil. Table I gives the results of the analytical work on all the soils analyzed. Phosphorus, sulphur, and volatile matter (loss on ignition) are reported as percentage of oven dry soil.

Sulphur is present in the soil either in the form of sulphates of calcium, magnesium, and iron, or in the form of organic matter. All the sulphates are quite soluble and are not readily adsorbed, so that they are leached out rapidly and only small amounts are present in the soil. On the other hand, the organic sulphur is insoluble and remains in the soil until oxidized to sulphates. One would expect, therefore, some sort of relation between the sulphur content of the soil and the volatile matter (loss on ignition), which is a rough method of determining the organic matter. The data in table I, however, indicate only a general relation, and that only when samples from the same soil type or closely related soil types are compared. The soil samples from Wisconsin are from the same soil type, but differ in amount of organic matter. There is also a difference in content of sulphur, and the higher sulphur content is found in the sample with the higher content of organic matter. This is true for both surface soil and subsoil. The Michigan

TABLE I

| Sample no. | Soil strata (inches) | Name of farm or farm owner | Location | Percentage of volatile matter | Percentage of sulphur | Percentage of phosphorus |
|---|---|---|---|---|---|---|
| 1 A... | 0–6 | Wah-Bee-Mee-Mee farm | Michigan | 2.076 | 0.0158 | 0.0360 |
| 1 B... | 7–14 | Wah-Bee-Mee-Mee farm | Michigan | 2.341 | 0.0157 | 0.0330 |
| 1 C... | 15–24 | Wah-Bee-Mee-Mee farm | Michigan | 2.662 | 0.0216 | 0.0305 |
| 2 A... | 0–6 | Wah-Bee-Mee-Mee farm | Michigan | 4.988 | 0.0486 | 0.0518 |
| 2 B... | 7–14 | Wah-Bee-Mee-Mee farm | Michigan | 4.481 | 0.0405 | 0.0561 |
| 3 A... | 0–6 | Wah-Bee-Mee-Mee farm | Michigan | 2.863 | 0.0183 | 0.0390 |
| 3 B... | 7–14 | Wah-Bee-Mee-Mee farm | Michigan | 2.522 | 0.0159 | 0.0324 |
| 4 A... | 0–6 | Wah-Bee-Mee-Mee farm | Michigan | 4.862 | 0.0361 | Not determined |
| 4 B... | 7–14 | Wah-Bee-Mee-Mee farm | Michigan | 3.754 | 0.0263 | Not determined |
| 5 A... | 0–6 | Wah-Bee-Mee-Mee farm | Michigan | 4.311 | 0.0319 | 0.0514 |
| 5 B... | 7–14 | Wah-Bee-Mee-Mee farm | Michigan | 3.822 | 0.0283 | 0.0468 |
| 5 C... | 15–24 | Wah-Bee-Mee-Mee farm | Michigan | 3.462 | 0.0177 | 0.0305 |
| 6 A... | 0–6 | Everett's farm | Ohio | 3.631 | 0.0232 | 0.0788 |
| 6 B... | 7–14 | Everett's farm | Ohio | 2.466 | 0.0140 | 0.0411 |
| 7 A... | 0–6 | Arnold's farm | Ohio | 4.642 | 0.0334 | 0.0771 |
| 7 B... | 7– | Arnold's farm | Ohio | 2.984 | 0.0195 | 0.0423 |
| 8 A... | 0–6 | Jacoby's farm | Ohio | 5.228 | 0.0281 | 0.0582 |
| 8 B... | 7– | Jacoby's farm | Ohio | 3.148 | 0.0050 | 0.0326 |
| 9 A... | 0–6 | Jacoby's farm | Ohio | 14.327 | 0.0905 | 0.0939 |
| 9 B... | 7– | Jacoby's farm | Ohio | 5.969 | 0.0194 | 0.0343 |
| 10 A... | 0–6 | Wager's farm | Wisconsin | 8.116 | 0.0351 | 0.0744 |
| 10 B... | 7– | Wager's farm | Wisconsin | 6.954 | 0.0202 | 0.0649 |
| 11 A... | 0–6 | Wager's farm | Wisconsin | 6.836 | 0.0245 | 0.0795 |
| 11 B... | 7– | Wager's farm | Wisconsin | 4.043 | 0.0124 | 0.0457 |
| 12..... | 0–6 | Ross's farm | Indiana | 5.758 | 0.0172 | 0.1054 |
| 13..... | 0–6 | Carr's farm | Indiana | 4.721 | 0.0165 | 0.0628 |
| 14..... | 0–6 | Reich's farm | Indiana | 4.075 | 0.0118 | 0.0490 |
| 15..... | 0–6 | Bentley's farm (cropped soil) | Indiana | 4.809 | 0.0155 | 0.0566 |
| 16..... | 0–6 | Bentley's farm (virgin soil) | Indiana | 5.249 | 0.0233 | 0.0564 |
| 17..... | 0–6 | Barnett's farm | Indiana | 4.462 | 0.0183 | 0.0492 |
| 18..... | 0–6 | McCulloch's farm | Indiana | 4.807 | 0.0155 | 0.0578 |
| 19..... | 0–6 | Adina farm | Kentucky | 7.024 | 0.0258 | 0.1897 |
| 20..... | 0–6 | Adina farm | Kentucky | 4.526 | 0.0232 | 0.0799 |
| 21..... | 0–6 | Adina farm | Kentucky | 7.496 | 0.0131 | 0.1636 |
| 22..... | 0–6 | Adina farm | Kentucky | 4.884 | 0.0122 | 0.1208 |
| 23..... | 0–6 | Adina farm | Kentucky | 4.318 | 0.0206 | 0.0768 |
| 24..... | 0–6 | Marshall's farm | Kentucky | 5.517 | 0.0264 | 0.1377 |
| 25..... | 0–6 | Downing's farm | Kentucky | 5.466 | 0.0159 | 0.0977 |
| 26..... | 0–6 | Downing's farm | Kentucky | 5.229 | 0.0236 | 0.1765 |
| 27..... | 0–6 | Downing's farm | Kentucky | 5.327 | 0.0153 | 0.1370 |
| 28..... | 0–6 | Gentry and Curry's farm | Kentucky | 6.021 | 0.0245 | 0.2355 |
| 29..... | 0–6 | Scott's farm | Kentucky | 5.088 | 0.0235 | 0.1500 |
| 30..... | 0–6 | Sharp's farm | Kentucky | 6.540 | 0.0161 | 0.1779 |
| 31..... | 0–6 | Moore's farm | Kentucky | 4.723 | 0.0253 | 0.1007 |
| 32..... | 0–6 | Fowler's farm | Kentucky | 5.051 | 0.0250 | 0.1727 |
| 33..... | 0–6 | Watt's farm | Kentucky | 5.836 | 0.0163 | 0.1306 |
| 34..... | 0–6 | Tuomey's farm | Kentucky | 11.105 | 0.0313 | 0.3407 |

soil samples are also quite similar in texture. Here again we find a high sulphur content with a high organic matter content, and a low sulphur content with a low organic matter content. When we compare different soil types or samples from the same type but from fields which have been cropped differently, however, there is little evidence of any relation. Samples 7 B and 9 B have approximately the same sulphur content, yet the volatile matter in the latter is twice that in the former. Both these samples are subsoils from Ohio, and were taken from fields that were not far apart, but 7 B is on upland silt loam while 9 B is a muck soil. Again, the cropped soil (no. 15) and the virgin soil (no. 16) from Bentley's farm, Indiana, differ only slightly in volatile matter, but differ widely in sulphur content. Gentry and Curry's soil (no. 28) has slightly less volatile matter than Sharp's soil (no. 30), but considerably more sulphur. Sample 10 A from Wager's farm in Wisconsin is a fine sandy loam soil with very little clay but a large amount of organic matter, as may be recognized by its black color, yet it contains considerably less sulphur than sample 2 A from the Wah-Bee-Mee-Mee farm in Michigan, which is also a sandy loam soil, containing considerable coarse sand with sufficient organic matter to give a black color.

It seems, then, that from the sulphur standpoint, as well as the nitrogen standpoint, the character of the organic matter is of more importance than the amount. Sulphur, like nitrogen, is mainly present in the proteins, so that a small amount of high protein organic matter, such as one would obtain by plowing under legumes, would be more valuable than a larger quantity of organic matter from wheat or oat straw or cornstalks. It seems probable also that the proteins are more readily decomposed than the non-protein organic matter, so that the sulphur and nitrogen would be oxidized more rapidly than the carbon, and the sulphur and nitrogen content might become quite low when there was still a considerable amount of carbonaceous organic matter in the soil.

In all the samples analyzed, the sulphur content was less than the phosphorus content. One of the samples from Ohio which was taken in a low wet place was a muck, very high in organic matter. This soil had nearly as much sulphur as phosphorus in

the surface soil (no. 9 A), but the subsoil (no. 9 B) had only a little more than half as much sulphur as phosphorus. The difference between the sulphur and phosphorus contents in one of the Michigan soils was not great. The surface soil (no. 2 A) contained 0.0486 per cent sulphur and 0.0518 per cent phosphorus, while the subsoil (no. 2 B) contained 0.0405 per cent sulphur and 0.0561 per cent phosphorus. All the other samples were much higher in phosphorus than in sulphur. The difference was very great in one of the Indiana soils, which had over six times as much phosphorus as sulphur, and in the Kentucky soils, in most of which the phosphorus content was from five to eleven times as much as the sulphur. In two of the Kentucky soils the phosphorus content was only three times as much as the sulphur, and in one only four times as much.

The Michigan soils, samples 1–5, were taken on the Wah-Bee-Mee-Mee farm at White Pigeon, Michigan. Samples 1 and 5 were sampled to three depths and all the others to two depths. These soils are alluvial sandy loams, varying from light brown to dark brown on the surface and grading into a yellow sandy subsoil containing some gravel. The light colored samples contained more sand in both surface and subsoil and were lower in volatile matter, sulphur, and phosphorus, than the darker colored ones. All were low in both sulphur and phosphorus, but the sulphur is lower than phosphorus in all the samples. With the exception of sample 1, the sulphur was always lower in the subsoil than in the surface soil.

The Ohio soils, samples 6–9, were taken near Copley, Ohio. Nos. 6, 7, and 8 are upland silt loams containing some sand. The surface soil is a yellow brown grading into a uniformly light yellow subsoil, which indicates good underdrainage as well as good surface drainage. These soils apparently belong to the type mapped as the Wooster silt loam. The sulphur content was low in both surface and subsoil, while the phosphorus content was fairly good in the surface but low in the subsoil. In every sample the subsoil was lower in volatile matter, sulphur, and phosphorus than the corresponding surface soil.

Sample 9 is poorly drained, and the surface soil has a large amount of organic matter with some silt, sand, and a little clay.

The subsoil has much less organic matter, but the proportion of its other constituents is about the same as in the surface. The surface soil is very high in volatile matter, sulphur, and phosphorus, while the subsoil is very low in both sulphur and phosphorus.

The Wisconsin soils, samples 10 and 11, are from near Beloit, Wisconsin. They are fine sandy loams, dark brown on the surface and a lighter brown in the subsoil. In both samples the volatile matter, sulphur, and phosphorus are higher in the surface soil than in the subsoil. The sulphur content is low in both surface soil and subsoil in both samples, but the phosphorus is good in the surface soil of both samples, fair in the subsoil of sample 10, and poor in the subsoil of sample 11. Both sulphur and phosphorus are lower in the subsoil than the surface soil in both samples.

The Indiana soil samples (nos. 12–18) were taken near Charlestown, Clark County, Indiana. This region is underlain by limestone rock, but the rock has been covered by a thick layer of windblown material, from which most of the soils were formed. All the soils sampled were formed from this windblown material except no. 12, which was taken on the bluff of a small stream where there was considerable erosion. It seems that the erosion has removed the greater part of the windblown material, and to a large extent the soil is formed from the underlying limestone. This is probably the reason why this sample resembles in general appearance and in chemical composition the Kentucky soils rather than the adjacent soils from the windblown material or loess. Sample 12 has a light brown silt loam surface soil grading into a reddish yellow subsoil. Like the other Indiana soils, the volatile matter and sulphur are low, but the phosphorus is high like most of the Kentucky soils.

The loessal soils include two types, the one with good natural underdrainage and the other with poor drainage. The former, which includes samples 15–18, is a yellow gray silt loam in the surface soil and a yellow silt loam in the subsoil. The latter, which includes samples 13 and 14, has a gray or slightly yellowish gray silt loam surface soil underlain by a gray or gray and yellow mottled silt loam subsoil. Both are poorly drained, but sample 13 is more nearly level and has more gray color in both surface and subsoil. All the samples from both types are low in volatile matter, sulphur,

and phosphorus. Samples 15 and 16 were taken a few rods apart, the former from a field which had been in alfalfa for several years, and the latter from virgin land. Both have practically the same phosphorus content, but the sulphur is much higher in the virgin soil.

All the soil samples from Kentucky (nos. 19–34) are residual limestone soils, but no. 34 was derived from the Trenton limestone, which is high in phosphorus, while the others are all from the Cincinnati limestone, but no. 28 was taken from soil derived from Cincinnati limestone, but it was only a short distance from the division line between the Cincinnati and Trenton formations, and had probably received some material from the Trenton formation. Samples 19–27 are from Mason County, while samples 28–34 are from Mercer County. Samples 19 and 21 are clay loams, while 20 and 22–27 are silt loams. All are light brown to grayish brown in color. Sample 34 is a heavy clay loam, sample 28 is a heavy silt loam or light clay loam, while samples 29–33 are silt loams. Samples 31 and 33 are quite gray in color, and 33 contains iron concretions. No. 31 is known locally as white oak land, and both are recognized as poor soils. All the other samples are light brown except no. 34, which is a grayish brown. All the Kentucky soils are low in volatile matter except the clay loams, in which part of the volatile matter is probably water of combination. All are low in sulphur, no. 34 being the only one above 0.03 per cent. This sample is from the Trenton formation and contains many unweathered fragments of limestone. It is possible that the sulphur content as well as the phosphorus content of the Trenton limestone may be higher than in other formations. No. 34 contains 0.3407 per cent of phosphorus, which is eleven times as great as the sulphur content. This is much higher than any of the others, but all the others are high in phosphorus.

RELATION BETWEEN AMOUNTS OF SULPHUR AND PHOSPHORUS REMOVED BY CROPS AND SULPHUR AND PHOSPHORUS CONTENTS OF SOILS.—A better idea of the supply of sulphur and phosphorus in the soil can be obtained if the pounds per acre of these elements found in the surface soil is compared with the amounts removed by some of our common crops. Table II gives the amounts of sulphur

and phosphorus removed by some of the common crops. The yields per acre and the amounts of phosphorus removed by these yields are taken from HOPKINS and PETTIT's (34) table, while the amounts of sulphur removed are computed from HART and PETERSON's analyses.

As pointed out by HOPKINS and PETTIT (34), these yields are exceptionally large, but they have been obtained by some farmers, and others may obtain them under proper systems of farming. If, however, smaller yields are removed, it will not prevent soil depletion, but will only delay soil exhaustion if the elements removed

TABLE II

POUNDS PER ACRE REMOVED BY FARM CROPS

| CROP | YIELD PER ACRE | POUNDS PER ACRE REMOVED ANNUALLY | |
|---|---|---|---|
| | | Sulphur | Phosphorus |
| Corn, grain | 100 bushels | 7.8 | 17.0 |
| Oats, grain | 100 bushels | 5.8 | 11.0 |
| Wheat, grain | 50 bushels | 5.1 | 12.0 |
| Timothy, hay | 3 tons | 11.4 | 9.0 |
| Clover, hay | 4 tons | 13.0 | 20.0 |
| Alfalfa, hay | 8 tons | 46.0 | 36.0 |
| Potatoes | 300 bushels | 24.7 | 13.0 |

are not returned in some form. In actual practice, failure to return to the soil the elements of plant food which are removed in the crops will result in a gradual decrease in yields, so that the amounts of plant food removed will gradually become less. It is impossible to determine the time when complete exhaustion will take place, but a comparison of the amounts of plant food removed by large crops with the amounts present in the soil will emphasize the importance of renewing the supply in the soil before the soil supply is reduced below that necessary for satisfactory crop yields. Table III gives the pounds per acre of sulphur and phosphorus in the surface soils analyzed and the number of years' supply of each for several common farm crops, if maximum crops are removed, such as are given in table II.

Table III shows that all the soils are too low in sulphur to grow alfalfa for 40 years, while 22 of them have phosphorus enough to

grow alfalfa 40 years or longer, provided, of course, none of these elements is added in any way and none removed except in the crops. Sample 9A, which has the highest sulphur content, has sulphur

TABLE III

POUNDS PER ACRE OF SULPHUR AND PHOSPHORUS AND NUMBER OF YEARS' SUPPLY FOR VARIOUS CROPS IF MAXIMUM CROPS ARE REMOVED

| Soil no. | Sulphur | | | | | | Phosphorus | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds per acre in soil | No. of years' supply for | | | | | Pounds per acre in soil | No. of years' supply for | | | | |
| | | Corn | Wheat | Timothy | Clover | Alfalfa | | Corn | Wheat | Timothy | Clover | Alfalfa |
| 1A | 316 | 40 | 62 | 28 | 24 | 7 | 720 | 42 | 60 | 80 | 36 | 20 |
| 2A | 972 | 125 | 191 | 85 | 75 | 21 | 1036 | 61 | 86 | 115 | 52 | 29 |
| 3A | 366 | 47 | 72 | 30 | 28 | 8 | 780 | 46 | 63 | 83 | 39 | 22 |
| 4A | 722 | 93 | 142 | 63 | 56 | 16 | ..... | ..... | ..... | ..... | ..... | ..... |
| 5A | 638 | 82 | 125 | 56 | 49 | 14 | 1028 | 60 | 86 | 114 | 51 | 29 |
| 6A | 464 | 60 | 91 | 41 | 36 | 10 | 1576 | 93 | 131 | 175 | 79 | 44 |
| 7A | 668 | 86 | 131 | 60 | 51 | 14 | 1542 | 91 | 129 | 171 | 77 | 43 |
| 8A | 562 | 72 | 110 | 50 | 43 | 12 | 1164 | 68 | 97 | 129 | 58 | 32 |
| 9A | 1810 | 232 | 355 | 159 | 139 | 39 | 1878 | 110 | 156 | 209 | 94 | 52 |
| 10A | 702 | 90 | 138 | 62 | 54 | 15 | 1488 | 88 | 124 | 165 | 74 | 41 |
| 11A | 490 | 63 | 96 | 43 | 38 | 11 | 1590 | 94 | 133 | 177 | 80 | 44 |
| 12 | 344 | 44 | 67 | 30 | 26 | 7 | 2108 | 124 | 176 | 234 | 105 | 59 |
| 13 | 330 | 42 | 65 | 29 | 25 | 7 | 1256 | 74 | 105 | 139 | 63 | 35 |
| 14 | 236 | 30 | 46 | 21 | 18 | 5 | 980 | 58 | 82 | 109 | 49 | 27 |
| 15 | 310 | 40 | 61 | 28 | 24 | 7 | 1132 | 67 | 94 | 126 | 57 | 31 |
| 16 | 466 | 60 | 91 | 41 | 36 | 10 | 1128 | 66 | 94 | 125 | 56 | 31 |
| 17 | 366 | 47 | 72 | 32 | 28 | 8 | 984 | 58 | 82 | 109 | 49 | 27 |
| 18 | 310 | 40 | 61 | 28 | 24 | 7 | 1156 | 68 | 96 | 128 | 58 | 32 |
| 19 | 516 | 66 | 101 | 45 | 40 | 11 | 3794 | 223 | 316 | 422 | 190 | 105 |
| 20 | 464 | 60 | 91 | 41 | 36 | 10 | 1508 | 94 | 133 | 177 | 80 | 44 |
| 21 | 262 | 34 | 51 | 23 | 20 | 6 | 3272 | 192 | 273 | 364 | 164 | 91 |
| 22 | 244 | 31 | 48 | 22 | 19 | 5 | 2596 | 153 | 216 | 288 | 130 | 72 |
| 23 | 412 | 53 | 88 | 36 | 32 | 9 | 1536 | 90 | 128 | 171 | 77 | 43 |
| 24 | 528 | 68 | 104 | 46 | 41 | 11 | 2754 | 162 | 230 | 306 | 138 | 77 |
| 25 | 318 | 41 | 64 | 28 | 24 | 7 | 1954 | 115 | 163 | 216 | 98 | 54 |
| 26 | 472 | 61 | 93 | 41 | 36 | 10 | 3530 | 208 | 294 | 392 | 177 | 98 |
| 27 | 306 | 39 | 50 | 27 | 24 | 7 | 2740 | 161 | 228 | 304 | 137 | 76 |
| 28 | 490 | 63 | 96 | 43 | 38 | 11 | 4710 | 277 | 393 | 523 | 236 | 131 |
| 29 | 470 | 60 | 92 | 41 | 36 | 10 | 3000 | 176 | 250 | 333 | 150 | 83 |
| 30 | 322 | 41 | 63 | 28 | 25 | 7 | 3558 | 209 | 296 | 395 | 178 | 99 |
| 31 | 506 | 65 | 99 | 44 | 39 | 11 | 2014 | 118 | 168 | 224 | 101 | 56 |
| 32 | 500 | 64 | 98 | 44 | 38 | 11 | 3454 | 203 | 288 | 384 | 173 | 96 |
| 33 | 326 | 42 | 64 | 29 | 25 | 7 | 2612 | 154 | 218 | 290 | 131 | 73 |
| 34 | 626 | 80 | 122 | 55 | 48 | 14 | 6814 | 401 | 568 | 757 | 341 | 189 |

enough for 39 years of alfalfa and phosphorus enough for 52 years of alfalfa. Only one other soil, no. 2 A, had enough sulphur for 20 years of alfalfa, while three soils, nos. 19, 28, and 34, have enough

phosphorus for 100 or more years of alfalfa. No. 34 has phosphorus enough to grow alfalfa 189 years, but sulphur enough for only 14 years. The phosphorus content of no. 28 is sufficient to grow alfalfa for 131 years, but the same crop would deplete the sulphur in 11 years. All these soils have sufficient phosphorus to grow maximum yields of alfalfa for 20 years or longer, while all but two would be depleted of sulphur in less than 20 years.

Of the other crops mentioned, corn, wheat, and clover remove smaller amounts of sulphur than phosphorus; while timothy, like alfalfa, removes more sulphur than phosphorus. Timothy, however, removes only about one-fourth as much sulphur, and one-fourth as much phosphorus as alfalfa, so that the supply of each would last correspondingly longer, yet soil 9A is the only one that carries sufficient sulphur for 100 crops of timothy. Soil 9A has sulphur enough to grow timothy 159 years, clover 139 years, corn 232 years, and wheat 355 years. No. 34 has phosphorus enough for 401 corn crops, 568 wheat crops, and 341 clover crops; yet the sulphur would be depleted by 80 corn crops, 122 wheat crops, or 48 clover crops. The lowest phosphorus content is in soil 1A, a sandy loam soil, which has 720 pounds of phosphorus in the surface 7 inches of soil. The phosphorus in this soil would be depleted by growing corn 42 years, wheat 60 years, timothy 80 years, clover 36 years, or alfalfa 20 years. In the same soil the sulphur would be removed by 40 years of corn, 62 of wheat, 28 of timothy, 24 of clover, or 7 of alfalfa.

Table III shows the importance of both sulphur and phosphorus if maximum crops of legumes, particularly alfalfa, are to be grown. It also shows that, in most soils, sulphur is more likely to be deficient than phosphorus. It does not take into account the leaching of these elements from the soil, which is practically nil in the case of phosphorus and very high in the case of sulphur; nor the supply in the rain water, which is nil in the case of phosphorus and may be quite high in the case of sulphur near cities in the humid regions. Whether the amount of sulphur lost in the drainage water exceeds that gained in the rain water is still unknown. It is certain that the amount of leaching will vary with the character of the soil, the rainfall, and the character of the plant growth. The amount of

sulphur in the rain water will vary with the rainfall and the nearness to cities where large amounts of soft coal are used. It is possible that, in some places under certain conditions, the amount of sulphur brought down in the rain water will equal or exceed that lost in the drainage, but that in other places and under other conditions the loss will exceed the gain. Field experiments are needed to see whether the plants will respond to sulphur fertilization under field conditions. Remarkable responses were obtained by JUDGE PETERS, JOHN BINNS, and EDMUND RUFFIN in the Eastern United States (CROCKER, 15), and have recently been obtained on the Pacific Coast by REIMER and TARTAR (58) in Oregon, and by OLSON (54) in Washington. To secure further information along this line, cooperative experiments were conducted on some farms in Indiana and Kentucky from which some of the samples reported in table I were taken.

### COOPERATIVE FIELD EXPERIMENTS WITH GYPSUM

The field experiments were conducted in cooperation with the farm owners. The farm owners were to apply gypsum and report on the effect on yields, if any. Some of the farmers failed to make any report, and those who did gave no weights, so that the results are not as satisfactory as could be desired. Results reported are as follows.

In the Indiana experiments, gypsum was applied to alfalfa, red clover, and tobacco. The only report received was with regard to the tobacco. This tobacco field was on the farm of Mr. Ross, southwest of Charlestown, Indiana. This is the field from which sample 12 was taken, and, as shown in tables I and III, is low in sulphur and high in phosphorus. Mr. Ross reports a marked increase in yield of tobacco from the use of gypsum on this field, but gives no quantitative data.

Gypsum was applied to alfalfa, red clover, sweet clover, and tobacco in Mason County, Kentucky. The crops were injured so badly by weather conditions, however, that no results were obtained.

In Mercer County, Kentucky, gypsum was applied to tobacco, clover, and alfalfa. Of the farmers responding, Mr. SHARP reported no increase in tobacco, while Mr. FOWLER reported an increase in

the second clover crop, and Mr. TUOMEY an increase in alfalfa. Neither of these men weighed the hay, so the results are not quantitative. Mr. SHARP's field, from which sample 30 was taken, is low in sulphur and high in phosphorus, but it showed evidences of being farmed hard, and was evidently low in nitrogen, which was probably the limiting element for a non-leguminous crop like tobacco. Mr. FOWLER's soil, no. 32, has 0.0250 per cent sulphur and 0.1727 per cent phosphorus, equivalent to 500 pounds of sulphur, and 3454 pounds of phosphorus, in the surface soil; so sulphur was probably the limiting element for clover. Mr. TUOMEY's field, sample 34, had 6814 pounds of phosphorus, the highest of the samples analyzed. This sample also contained small fragments of limestone, so that there was an abundance of lime. On the other hand, the sulphur content, 626 pounds, although higher than in many samples, is probably rather low for a plant like alfalfa, which uses such large quantities of sulphur.

These results are not conclusive, but it seems probable that sulphur may be a limiting element on some of these soils, and that gypsum is a satisfactory source of supply for this element. More field experiments are necessary in the humid part of the United States, and great care in conducting these experiments is necessary if satisfactory results are to be obtained. Experiments should be conducted through several years to avoid weather conditions, which may be the limiting factor in some years. On some soils drainage is necessary, and no fertilizer treatment will have any effect until this is done. Most soils in the humid part of the United States are acid. A large part of them are so acid that liming is necessary before any other treatment is effective, especially for leguminous crops. Table I shows a high phosphorus content in some of the soils reported in this paper, but those are exceptional soils. As a general rule soils are deficient in phosphorus, and farmers report increases in crop yields for the use of acid phosphate. It is impossible, however, to tell how much of the increase is due to the phosphorus and how much to the sulphur in the acid phosphate. A comparison of acid phosphate with rock phosphate and gypsum, and with gypsum alone, and rock phosphate alone would give some valuable results.

Many of the Illinois experiment fields include three check plots in each series. These check plots are all untreated and are only a short distance apart, yet some of them differ widely in crop yields. It is reasonable to assume that neighboring plots receiving the same fertilizer treatment would differ as widely. These differences due to factors not under the control of the investigators make the probable error large, and when only one plot of each treatment is used, the differences between plots with different treatments must be great before one can assume that the treatment has been effective. Where the differences are as great as in the work of REIMER and TARTAR (58) and of OLSON (54), there is no doubt that the treatment has been effective, but in many of the field experiments in different parts of the country the differences are too small to justify the conclusions drawn from them, as the probable error is so great. Where a number of plots of each treatment are used, the uncontrollable factors tend to neutralize each other and the probable error is reduced. As the number of plots of each treatment increases, smaller average differences are necessary to be significant. It seems probable that three plots of each treatment are necessary if satisfactory results are to be obtained. In the past investigators have had a tendency to scatter field experiments over a number of widely separated fields on the same soil type. It seems probable that more satisfactory results would be obtained if the work were confined to one field on each soil type, and each field had from three to five plots of each treatment.

## Summary

1. Composite soil samples from Indiana, Kentucky, Michigan, Ohio, and Wisconsin were analyzed for total sulphur, total phosphorus, and volatile matter (loss on ignition), and cooperative fertilizer experiments with gypsum were conducted in fields in Indiana and Kentucky.

2. The analytical data show a general relation between the sulphur content and loss on ignition in soil samples from the same soil type or closely related soil types, but the relation is not apparent when different soil types are compared.

3. The sulphur contents in the surface soil vary from 0.0118 to 0.0905 per cent, while the phosphorus contents vary from 0.0360 to 0.3407 per cent. All the upland soils and most of the alluvial soils are low in sulphur. Most of the Kentucky soils and one of the Indiana soils are high in phosphorus. This is undoubtedly due to the influence of the rock from which the soils were formed, as all the Kentucky samples were from soils derived either from the Trenton limestone or the Cincinnati limestone, both of which are high in phosphorus content.

4. The sulphur and phosphorus contents were calculated to pounds per acre in the surface soil, and compared with the amounts of sulphur and phosphorus removed by maximum crops of corn, wheat, timothy, clover, and alfalfa. The highest sulphur content is sufficient for only 39 years of alfalfa, 139 of clover, 159 of timothy, 355 of wheat, or 232 of corn; while the lowest sulphur content is sufficient for only 5 years of alfalfa, 18 of clover, 21 of timothy, 46 of wheat, or 30 of corn. The lowest phosphorus content is equal to the amount removed by 42 years of corn, 60 of wheat, 80 of timothy, 36 of clover, or 20 of alfalfa. On the other hand, it would take 401 years of corn, 568 of wheat, 757 of timothy, 341 of clover, or 189 of alfalfa to remove as much phosphorus as is found in the soil with the highest phosphorus content.

5. On some of the soils tobacco, clover, and alfalfa have been benefited by the use of gypsum. The results, however, are not quantitative. More field experiments are needed and greater care should be taken to eliminate other factors as far as possible. Each treatment should be replicated to reduce the probable error.

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## LITERATURE CITED


1. AMES, J. W., and RICHMOND, T. E., Fermentation of manure treated with sulphur and sulphates. Changes in nitrogen and phosphorus content. Soil Science **4**:79–89. 1917.
2. ———Effect of sulphofication and nitrification on rock phosphate. Soil Science **6**:351–364. 1918.
3. BOULLANGER, E., and DUGARDIN, M., Mechanisme de l'action du soufre. Compt. Rend. Acad. Sci. Paris **155**:327–329. 1912.
4. BRADLEY, C. E., The reaction of lime and gypsum on some Oregon soils. Jour. Ind. and Engin. Chem. **2**:529–530. 1910.
5. BREZEALE, J.F., and BRIGGS, L.J., Concentration of potassium in orthoclase solutions not a measure of its availability to wheat seedlings. Jour. Agric. Res. **20**:615–621. 1921.
6. BRIGGS, L. J., and BREZEALE, J. F., Availability of potash in certain orthoclase bearing soils as affected by lime or gypsum. Jour. Agric. Res. **8**:21–28. 1917.
7. BRIOUX, CH., and GUERBET, M., L'action fertilisante du soufre. Annales Sci. Agron. **30**:395–396. 1913.
8. BROOKS, W. P., Alfalfa. Mass. Agric. Exp. Sta. Bull. 154. 1914 (p. 158).
9. ———, Phosphates in Massachusetts agriculture, importance, selection, and use. Mass. Agric. Exp. Sta. Bull. 162. 1915.
10. BROWN, P. E., and GWINN, A. R., Effect of sulphur and manure on availability of rock phosphate in soil. Iowa Agric. Exp. Sta. Res. Bull. **43**: 373–379. 1917.
11. BROWN, P. E., and KELLOGG, E. H., Sulphofication in soils. Iowa Agric. Exp. Sta. Res. Bull. **18**:104–110. 1914.
12. BROWN, P. E., and WARNER, H. W., The production of available phosphorus from rock phosphate by composting with sulphur and manure. Soil Science **4**:269–282. 1917.
13. BROWNE, J. D., The field book of manures or the American muck book. 1854 (pp. 68–75).
14. BRUCKNER, W. H., American manures. 1872 (p. 65).
15. CROCKER, WM., History of the use of gypsum as a fertilizer. (Unpublished article.)
16. DEMOLON, M. A., Recherches sur l'action fertilisante du soufre. Compt. Rend. Acad. Sci. Paris **156**:725–728. 1913.
17. DULEY, F. L., The relation of sulphur to soil productivity. Jour. Amer. Soc. Agron. **8**:154–160. 1916.
18. DYMOND, T. S., HUGHES, F., and JUPE, C. W. C., The influence of sulphates as manures upon the yield and feeding value of crops. Jour. Agric. Sci. **1**: 217–229. 1905.
19. EATON, S. V., Sulphur content of soils and its relation to plant nutrition. (Unpublished article.)

20. ELLETT, W. B., and HARRIS, W. G., Cooperative experiments for the composting of phosphate rock and sulphur. Soil Science, **10**:315–325. 1920.
21. FEILITZEN, H. VON, Über die Verwendung der Schwefelblüte zur Bekämpfung des Kartoffelschorfes und als indirekes Düngemittel. Fühling's Landw. Zeit. **62**:239. 1913.
22. FRAPS, G. S., The effect of additions on the availability of soil potash, and the preparation of sugar humus. Texas Agric. Exp. Sta. Bull. 190. 1–30, 1916.
23. FRED, E. B., and HART, E. B., The comparative effect of phosphates and sulphates on soil bacteria. Wis. Agric. Exp. Sta. Res. Bull. 35. pp. 42–44. 1915.
24. GREAVES, J. E., CARTER, E. F., and GOLDTHORPE, H. C., Influence of salts on nitric nitrogen in soils. Jour. Agric. Res. **16**:107–135. 1919.
25. GRIFFITHS, A.B., A treatise on manures. 1889 (pp. 247–248).
26. HALL, A. D., Book of Rothamsted experiments. 1917.
27. HART, E. B., and PETERSON, W. H., Sulphur requirements of farm crops in relation to the soil and air supply. Wis. Agric. Exp. Sta. Res. Bull. no. 14. 1911.
28. ———, Sulphur requirements of farm crops. Jour. Amer. Chem. Soc. **33**:549. 1911.
29. HART, E. B., and TOTTINGHAM, W. E., Relation of sulphur compounds to plant nutrition. Jour. Agric. Res. **5**:233–248. 1915.
30. HEINRICH, R., Concerning the conservation of manure. E.S.R. **5**:329, 330. 1893–1894. Abst. from Landw. presse **20**:825. 1893.
31. HILGARD, E. W., Soils; their formation, properties, composition, and relation to climate and plant growth. 1906 (p. 43).
32. HOPKINS, C. G., Soil fertility and permanent agriculture. 1910 (pp. 39, 189).
33. HOPKINS, C. G., MOSIER, J. G., PETTIT, J. H., and READHIMER, J. E., Hardin County soils. Ill. Agric. Exp. Sta., Soil Report no. 3. 1912.
34. HOPKINS, C. G., and PETTIT, J. H., The fertility in Illinois soils. Ill. Agric. Exp. Sta. Bull. no. 123. 1908 (pp. 533–535).
35. HUNT, THOS. F., Soil fertility. Pa. State Coll. Bull. no. 90. 1909.
36. LAWES, J. B., and GILBERT, J. H., Report on the growth of red clover by different manures. Jour. Roy. Agric. Soc. **21**:194. 1860.
37. LIEBIG, J. VON, Principles of agricultural chemistry. 1855. Transl. by WM. GREGORY, p. 99.
38. LINT, H. C., The influence of sulphur on soil acidity. Jour. Ind. and Engin. Chem. **6**:747. 1914.
39. LIPMAN, C. B., and GERICKE, W. F., Does calcium carbonate or calcium sulphate treatment affect the solubility of the soil constituents? Univ. Calif. Publ. Agric. Sci. **3**:271–282. 1918.

40. ———, The significance of the sulphur in sulphate of ammonia applied to certain soils. Soil Science **5**:81–86. 1918.

41. LIPMAN, J. G., and JOFFE, J. S., The influence of initial reaction on the oxidation of sulphur and the formation of available phosphates. Soil Science **10**:327–332. 1920.

42. LIPMAN, J. G., and MCLEAN, H. C., Sulphur-phosphate composts under field conditions. Soil Science **5**:243–250. 1918.

43. LIPMAN, J. G., MCLEAN, H. C., and LINT, H. C., Sulphur oxidation in soils and its effect on the availability of mineral phosphates. Soil Science **2**:498–538. 1916.

44. LYON, T. L., and BIZZELL, J., Lysimeter experiments. Cornell Univ. Agric. Exp. Sta. Mem. 12. 1918.

45. MCCALL, A. G., and SMITH, A. M., Effect of manure-sulphur composts upon the availability of the potassium of greensands. Jour. Agric. Res. **19**:239–255. 1920.

46. MCCOOL, M. M., and MILLAR, C. E., Effect of calcium sulphate on the solubility of soils. Jour. Agric. Res. **19**:47–54. 1920.

47. MACINTIRE, W. H., WILLIS, L. G., and HOLDING, W. A., The divergent effects of lime and magnesia upon the conservation of soil sulphur. Soil Science **4**:231–237. 1917.

48. MCLEAN, H. C., The oxidation of sulphur by micro-organisms in its relation to the availability of phosphates. Soil Science **5**:251–290. 1918.

49. MCMILLAR, P. R., Influence of gypsum upon the solubility of potash in soils. Jour. Agric. Res. **14**:61–66. 1918.

50. MARES, M. H., Des transformations que subit le soufre en poudre (fleur de soufre et soufre trituré) quand il est répandu sur le sol. Compt. Rend. Acad. Sci. Paris **69**:974–979. 1869.

51. MILLER, H. G., Sulphates affecting plant growth and composition. Jour. Agric. Res. **17**:87–101. 1919.

52. MORSE, F. W., and CURRY, B. E., The availability of the soil potash in clay and clay loam soils. N. H. Agric. Exp. Sta. Bull. 142. pp. 49–51. 1909.

53. NOLTE, OTTO, Über die Ursache der stickstoffverluste aus Jauche und Stallmist. Landw. Vers. Stat. **96**:309–324. 1920.

54. OLSON, GEO. A., Unpublished work of the Chemistry Department, Washington State College.

55. PETERSON, W. H., Forms of sulphur in plant materials and their variation with the soil supply. Jour. Amer. Chem. Soc. **36**:1290–1300. 1914.

56. PFEIFFER, TH., and BLANCK, E., Landw. Vers. Stats. **83**:359–383. 1914.

57. PITZ, W., Effect of elemental sulphur and calcium sulphate on certain of the higher and lower forms of plant life. Jour. Agric. Res. **5**:771–780. 1916.

58. REIMER, F. C., and TARTAR, H. V., Sulphur as a fertilizer for alfalfa in Southern Oregon. Ore. Agric. Exp. Sta. Bull. 163. 1919.

59. ROBINSON, W. O., Inorganic composition of some American soils. U.S. Dept. Agric. Bull. 122. 1914.
60. ROBINSON, W. O., STEINKONIG, L. A., and FRY, W. H., Variation in chemical composition of soils. U.S. Dept. Agric. Bull. 551. 1917.
61. SCHREINER, O., The rôle of oxidation in soil fertility. U.S. Dept. Agric. Soils Bureau Bull. 56. pp. 30–42. 1909.
62. SHEDD, O. M., The sulphur content of some typical Kentucky soils. Ky. Agric. Exp. Sta. Bull. 174. 1913.
63. ———, Effect of sulphur on different crops and soils. Jour. Agric. Res. 11:91–103. 1917.
64. SHERBAKOFF, C. D., Potato scab and sulphur disinfection. Cornell Univ. Agric. Exp. Sta. Bull. 350. 738, 739. 1914.
65. SMITH, R. S., Some effects of potassium salts on soils. Cornell Univ. Agric. Exp. Sta. Mem. 35. p. 586. 1920.
66. STEWART, J. P., The fertilization of apple orchards. Pa. State Coll. Agric. Exp. Sta. Bull. 153. 1918.
67. STEWART, ROBERT, Sulphur in relation to soil fertility. Ill. Agric. Exp. Sta. Bull. no. 227. 1920.
68. SWANSON, C. O., and MILLER, R. W., The sulphur content of some typical Kansas soils and the loss of sulphur due to cultivation. Soil Science 3:139–148. 1917.
69. TRESSLER, D. K., The solubility of soil potash in various salt solutions. Soil Science 6:237–257. 1918.
70. VENDELMANS, HENRY, Manual of Manures. 1916 (p. 142).
71. VIVIEN, A., Abs. E. S. R. 17:951; from Monit. Sci. 4: ser. 19. no. 2. 773–779. 1905.
72. VOORHEES, E. B., Fertilizers. 1917. Revised ed., p. 116.
73. WARINGTON, R., Reprint from Jour. Chem. Soc. 47. 1885.

# CYCLIC MANIFESTATION OF STERILITY IN BRASSICA PEKINENSIS AND B. CHINENSIS

A. B. STOUT

(WITH SEVEN FIGURES)

The transition from asexual or vegetative growth to the condition of flower and fruit production in hermaphrodite plants is to be recognized as a most fundamental aspect of sexuality. Furthermore, the inter-relations that exist between vegetative and reproductive vigor and the influence of the former on the latter are reflected and exhibited in certain phenomena of sterility.

It is now certain that vegetative vigor and the internal inter-relations incident to it may limit reproductive vigor and sexuality. The limitation from these causes may take place in two ways: (1) they may interfere with or influence the morphological development of flowers or other reproductive organs, and (2) they may affect the functioning powers of organs that are fully formed. If these influences are marked, one or more types of sterility may appear.

Only recently observations have indicated that, at least in some cases, the compatibilities and the fertility of the sex organs may vary rather definitely within the cycle of vegetative and reproductive development characteristic of the particular species. A phenomenon of this sort is reported by EAST and PARK (4), who found that in the few plants which are self-compatible in certain species and hybrids of *Nicotiana*, the self-compatibility develops only at the end of the flowering period. Cases of cross-compatibility appearing only at the end of the period of bloom are reported also. A very decided case of the development of self-compatibility only at the close of the period of bloom was observed by the writer, in a plant of *Lythrum Salicaria*, and reported at the annual meeting of the Botanical Society of America for 1917. These observations suggested that new evidence on the old problem of the relation between vegetative vigor and reproductive vigor, as expressed in the formation of flowers and the functioning of the

parts in seed formation, may be obtained by experimental means from a study of the fluctuations in fertility that are to be seen in those feebly self-compatible individuals which are to be found in species in which general sexual incompatibilities are strongly developed.

A subsequent report of a more detailed study on this problem (STOUT 11), however, showed that in *Verbascum phoeniceum*, *Eschscholtzia californica*, and *Cichorium Intybus* the various grades of self-compatibility operate very uniformly throughout the entire period of bloom, and that there are in the feebly self-compatible plants of these species no specially marked tendencies to self-compatibility at any definite phase of the blooming period. It was also found that in *Nicotiana Forgetiana* Hyb. Hort. and in *Lythrum Salicaria* end-bloom self-compatibility develops as an infrequent individual variation rather than as a phenomenon characteristic of the self-compatible plants. In these species there is no cyclic production of fruits and seeds which would indicate a general relation between vegetative vigor and the development of self-compatibility.

Such a cyclic occurrence of self-compatibility was found, however, and reported for *Brassica pekinensis*, and it was noted that the highest degree of self-compatibility attained by any given plant appeared very uniformly during the period of mid-bloom. Further studies with this species have since been made which show this to be the rule for all those individuals that are self-compatible in any degree. Similar behavior has also been found in cultures of *Brassica chinensis* and in hybrids between this species and *B. pekinensis*. So far as known to the writer, this is the most uniform and definite case of a general and definite periodicity in the modification of sexual compatibilities within a blooming period. In these species, also, flower abortion appears in the transition of vegetative to reproductive vigor, exhibiting an influence of vegetative vigor on the morphological development of flowers.

## Material and methods

Several strains of the "head" sorts of *Brassica pekinensis*, commonly known as Chinese cabbage or Pe-tsai, and one strain of the loose-leaved or headless sort (the Nanking variety) were grown

from seeds furnished by the Office of Foreign Seed and Plant Introduction of the United States Department of Agriculture. The seeds of the strain of *B. chinensis* which have been grown were obtained from China by a Chinese student at Columbia University for the gardener in charge of the greenhouses belonging to the University, and the writer obtained seeds from the first lot of plants there grown. From controlled cross-pollinations between plants of the two species, seeds were obtained and plants of an $F_1$ hybrid progeny were grown.

The greater number of plants have been grown in pots in a greenhouse and brought into bloom during the winter and spring before they could suffer from the heat of summer. When thus grown, plants of the head varieties of *B. pekinensis* form a rather loose headlike rosette, much smaller and less compact than when grown under field culture, after which they shoot up into flower. Plants of the Nanking variety of *B. pekinensis* and plants of *B. chinensis* do not form a head even under the best of field culture; a very loose rosette of leaves develops, and this grades up into the leaves of the flowering stem. Pot grown plants of these species closely resembled field grown plants except that they were smaller.

A few plants of all strains have been grown to full maturity in the garden, both as spring and autumn crops. Such plants were larger than the pot grown plants and more flowers were produced, but their behavior in respect to fertility and sterility was identical with that of plants grown in the greenhouse. Special effort was taken to make controlled self-pollinations throughout the entire period of blooming.[1] Numerous plants have bloomed alone or in isolation from other species of *Brassica*, both in the greenhouses and in the field, and hand pollinations were made from one to four days apart as long as the plants bloomed. The plants not grown in isolation were "bagged." Flowering branches were inclosed in glassine paper bags on or within a day or two following the opening of the first flowers; the plants were visited at least twice a week (at first

[1] During the winter season of 1919–1920 the writer was greatly aided by the voluntary assistance of Mrs. MORTIMER J. FOX. Miss HESTER M. RUSK has assisted in the research and made many of the pollinations of the plants grown in 1920–1921. Through this efficient assistance and cooperation the many pollinations necessary to the research were accomplished.

many were visited daily), and pollen from fully dehiscent stamens in liberal amounts was placed on pistils of all freshly opened flowers. After the cyclic modification of self-compatibility was recognized, frequent cross-pollinations were made to test the functional power of pistils and stamens during the periods of self-incompatibility preceding and following the period of mid-bloom. The potency of the pollen has been studied by germination tests, and a cytological study of the phenomena of pollen tube growth and fertilization is under way.

### Sterility in Brassica pekinensis and B. chinensis

Three distinct and quite different types of sterility are in evidence during the period of bloom in both these species.

I. One type is to be classed in general with impotence (STOUT 12), but here two very distinct types of impotence may be observed. These may be described as (1) flower abortion of the first flowers, and (2) arrested development of the last flowers that start to form.

II. In some plants of both species, axial proliferations develop from the pistils of many flowers, and the pistils of such flowers are functionless in respect to fruit production.

III. Among the flowers that open fully and are capable of functioning in certain relations, various grades of incompatibilities are in evidence, and self-compatibility whenever present is most strong during the period of mid-bloom.

#### I. IMPOTENCE

(1) FLOWER ABORTION.—Frequently in *Brassica pekinensis* the first flowers on the main stalk and often also the first flowers on laterals are completely aborted. The flower buds remain small and do not open, but soon become dead and black. A rather characteristic case of flower abortion is shown in fig. 1, which is of a pot grown plant of *B. pekinensis* blooming in February. Nearly forty of the first flowers of the main branch aborted, after which the flowers were completely formed, normal in appearance, and fully capable of functioning in certain fertilizations. The uppermost lateral branch coming into bloom later than the main axis had only five flowers that aborted, and the next lower lateral had no aborted

flowers. On such plants the lateral branches which come into bloom at the time when the main branch is producing normal flowers as a rule have normal flowers from the first (figs. 1–3). This coordination between flowers opening simultaneously on different branches as to kind of development is very marked. At first view, this abortion of flowers appears to resemble the blasting of flowers which frequently occurs in all sorts of plants as the direct effect of unfavorable environmental influences, but here the phenomenon is due primarily to internal conditions. As grown in the various cultures, the plants came into bloom at various times, some were producing mid-bloom and potent flowers, while other plants by them and just coming into bloom showed flower abortion. The abortion, therefore, is essentially self-induced.

FIG. 1.—Typical case of flower abortion in plant of *Brassica pekinensis;* about forty of first flowers on main axis aborted; there are five such flowers on uppermost lateral and none on second lateral, showing correlation in morphological character according to time of blooming.

Flower abortion of the first flowers is the rule among plants of the varieties of *B. pekinensis* which form leafy heads and which are grown in the field under conditions which favor the development of heads. In such plants, if left to bloom, the flowering branches are at first inclosed within the head. At the time when the flowering branches first come to the light,

they are somewhat blanched and tender, and the first flowers are already aborted. This condition of itself suggests that, in this

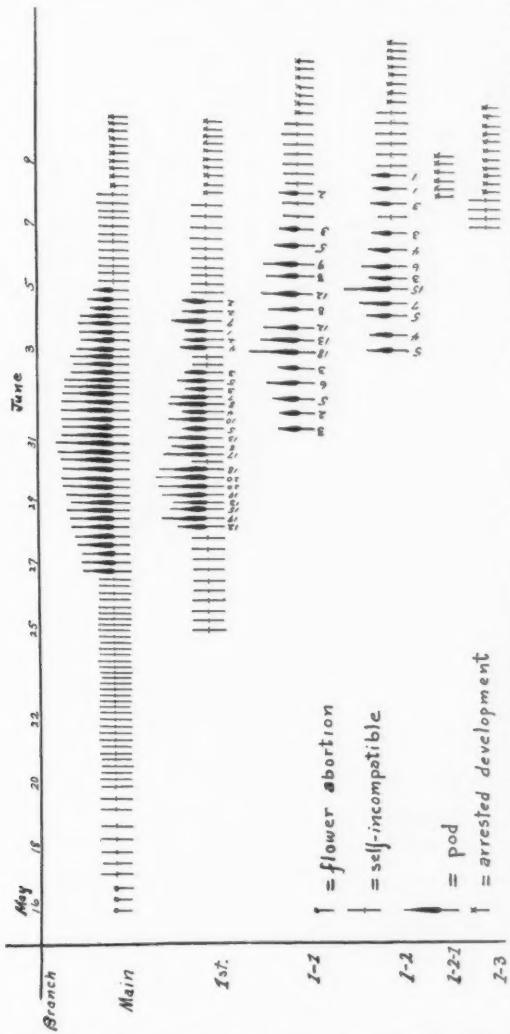


FIG. 2.—Chart showing distribution according to dates of flower abortion, self-incompatibility, self-compatibility, and arrested development on main branch and on uppermost lateral with all its laterals; relative sizes of pods indicated; number of seeds per pod given for all but main branch.

case, temperature and light conditions are important factors which are concerned in the abortion of the first flowers.

Flower abortion, however, is quite pronounced in many plants of *B. pekinensis* grown in pots and in which the head is scarcely

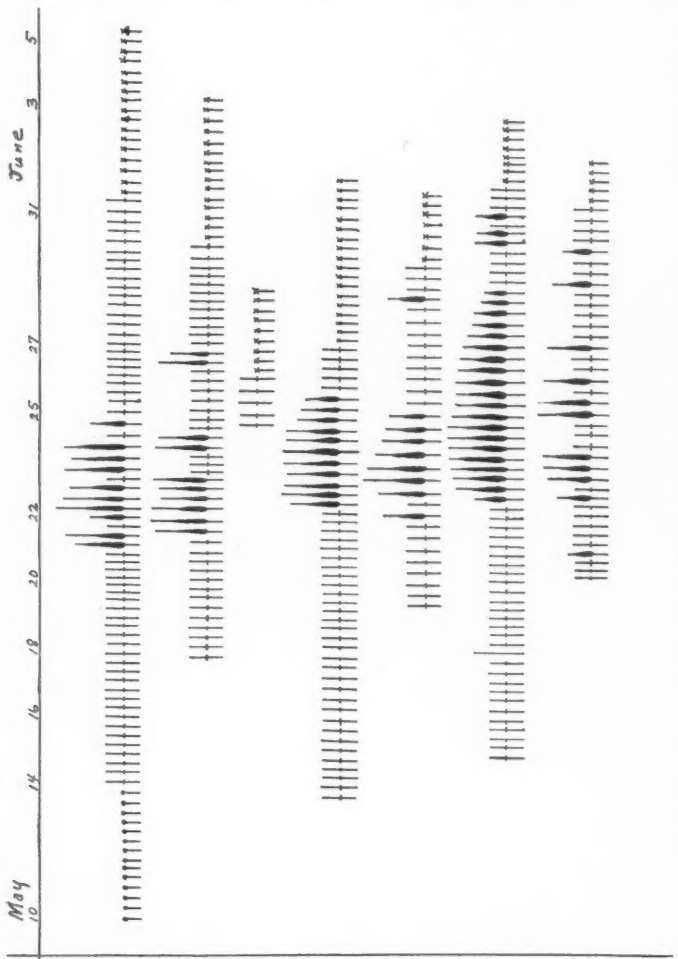


FIG. 3.—Chart for all flowering branches of plant; flower abortion, self-incompatibility, and self-compatibility all cyclic, and each closely coordinated in the various branches according to date of bloom.

developed. In the Nanking variety in which the leaves form only a loose rosette, about one-third of the plants grown have had some

aborted flowers, but usually only a few of the first flowers abort. Flower abortion also appears in many plants of *B. chinensis* which have very loose rosettes of leaves.

In these species flower abortion occurs as a transitional stage between a period of vigorous vegetative vigor and a period of flower formation and seed production. The plants which exhibit abortion are not able to pass at once into complete reproductive activity in producing potent flowers. The amount of abortion is greatest in the varieties of *B. pekinensis* in which vegetative vigor is most marked and in which excessive vegetative growth can readily be induced by good cultural conditions and which have been selected and bred for this feature. Flower abortion occurs in numerous plants of these sorts that are grown in pots, as it does in many plants of the loose-leaved kinds, but it apparently tends to be less marked in these.

Flower abortion is here undoubtedly correlated with the degree of vegetative vigor. It is not merely due to a stifling of flowers from simple direct injury because of inclosure within a head, however, but to a constitutional feature of which the formation of a leafy head or rosette is an extreme expression. In this sense the abortion of flowers is self-induced and to some degree hereditary. Usually the transition from aborted flowers to apparently normal flowers is sudden and complete (fig. 1). Sometimes, however, the first flowers to appear after the aborted ones, or the first flowers when there are no aborted ones, are poorly developed, are plainly immature and undersized, and especially in *B. chinensis* there may be premature opening.

(2) Arrested development of last flowers.—At least some of the last flowers which begin to form remain immature and functionless. In the first of such flowers the corollas wither quickly and may become dry and papery without falling. Then the flowers become smaller in size and more incomplete in development until at last they are mere stubs of tissue. Usually from six to ten flowers in these various stages of arrested development may be counted at the tip of each branch. On short, lower, lateral branches and on secondary or later laterals all of the flowers may fail to develop fully. This condition is shown in the illustrations. The distribution of flowers that fail to develop is indicated in figs. 2 and 3.

This type of sterility, of course, is very common in all sorts of flowering plants, and is clearly associated with old age and death of the entire plants or of the individual flowering branches. In these species of *Brassica* it is unusually conspicuous, and begins to develop when growth has ceased and parts of the plant, especially the basal leaves, are dying or even dead and falling from the plant. Flowers that have aborted or developed poorly at the beginning of the period of bloom, and those in which development is arrested, are all functionless. Their failure to produce fruit is entirely independent of any sort of fertilization. It is clearly due to impotence.

## II. Proliferation

In a few plants of several strains of both *Brassica chinensis* and *B. pekinensis*, noticeable axial proliferations develop. The axis anlage inclosed within the carpels of the pistil grows and branches until it bursts open the pistil. The pedicel of the flower enlarges; the proliferated branch may become several inches long and bear as many as twenty-five flowers, many of which are able to function in seed production. Proliferation may be regarded as the sterilization of a pistil by vegetative growth of the tissue beneath and within it. In the end it is the expression of a tendency to vegetative vigor which culminates in the production of many more pistils and stamens.

Although proliferation is often irregular in its distribution, it is most frequent during the earlier portion of the period of bloom. Frequently it is most highly developed in the first flowers of plants which show little or no flower abortion, but it often does appear later. The last flowers of those which open normally as a rule are free from proliferations. This abnormality is certainly to be regarded as an expression of excess vegetative vigor, as a result of which the axis about which flower parts are grouped resumes active vegetative growth. The stamens in many of the flowers whose axes proliferate seem to be normal, but the pistils are not productive of fruit.

Another type of excessive vegetative vigor is seen in the development of green leaves at the base of each flower, giving a leafy inflorescence. This has only been observed in a few plants, and

its possible relation to the production of flowers and to their impotence has not been determined.

### III. Physiological incompatibility

During the phase when the flowers are completely developed, many flowers are produced that are capable of producing pods and seeds. In general the plants produce such flowers in abundance, in succession for a period of about twenty days, and with continuous and rather rapid elongation of branches (cf. fig. 1 with 4 and 6). A free and indiscriminate functioning of the organs in seed production, however, is decidedly limited by incompatibilities in fertilization.

Self-incompatible plants.—Plants may be completely self-incompatible throughout, as was the case for the plant shown in fig. 4. The first six flowers on the main branch aborted, but the very first flowers on the three uppermost laterals were normal. A few flowers at the ends of the branches failed to develop. In all, about seventy flowers on the main branch, forty on each of the first and second laterals, and fifty on the third lateral were capable of functioning. Three lower branches, which bore together about one hundred normal flowers and were like the third lateral in general appearance, were not included in the photograph. This plant grew in isolation in a greenhouse, and self-pollinations were made by hand at least three times a week throughout the period of bloom. At least two hundred flowers were carefully self-pollinated, but not a pod resulted. The pods which were formed on this plant were all from compatible cross-pollinations. Six fine large pods near the base of the main stem were all from flowers that opened rather early; the two first flowers on the first lateral yielded fine pods to a cross; and large pods containing viable seeds were obtained by crossing some of the very last flowers to open normally on the main stem and on the first and second laterals. The stamens were apparently normal throughout the time when flowers opened normally; pollen from many stamens examined at different times was found to be plump and normal in appearance, and the use of pollen in certain crosses covering the entire period of normal bloom resulted in seeds. Such tests have been made repeatedly on

numerous plants with results as noted, which show that the failure to set seed to self-pollination is due to a sexual incompatibility between reproductive elements that are capable of functioning in certain other relations.

A total of 1371 plants of these two species of *Brassica* and hybrids between them have been tested at the time this is written, and of these 653 were found to be completely self-incompatible. Plants were thus classed when no pods developed to selfing at any time throughout the entire period of bloom. There were, however, several grades to be seen in respect to the length of time the pistils remained attached to the plant. In the plant shown in fig. 4, with few exceptions, the pistils of flowers

FIG. 4.—Plant of *B. pekinensis*, completely self-incompatible but producing good pods containing viable seeds to compatible crosses at any time while flowers are fully developed.

FIG. 5.—Feebly self-compatible plant of *B. chinensis;* first two flowers and last to open normally on main axis highly fertile in compatible cross.

selfed fell soon after the petals had fallen. In other plants, and especially plants of *B. chinensis*, nearly all the pistils of selfed flowers remained attached only during the period of mid-bloom.

SELF-COMPATIBLE PLANTS.—A total of 718 plants of the various cultures grown were self-compatible in some degree. For the

FIG. 6.—Plant of *B. pekinensis*, highly self-compatible during period of mid-bloom; no flower abortion; first flowers to bloom on laterals were self-compatible, showing correlation with main branch in physiological character according to time of bloom.

purpose of a general classification the self-compatibility was judged as *feeble*, *medium*, and *strong*, but there were many grades within each class with no sharp distinctions between them. The weakest grade includes the cases in which, most typically, a few small pods containing only aborted seeds developed. In some cases pods of good size were formed, as is shown in fig. 5, but the seeds were all

shriveled and not viable. Such plants were classed as feebly self-compatible. Plants whose self-compatibility was classed as medium produced some viable seeds. The number of pods, the number of shriveled seeds, and to some extent the number of viable seeds varied greatly among plants thus grouped. The plants classed as strongly self-compatible produced numerous pods, and the total number of viable seeds was high. In these also the number of pods, their size, and the numbers of viable and of shriveled seeds varied greatly. The various grades of self-compatibility were seen among sister plants that were as nearly identical as is possible in regard to vegetative vigor, number of branches and flowers produced, and as to calendar dates for period of blooming.

FIG. 7.—Plant of *B. chinensis;* no flower abortion; plant highly self-compatible; showing cycle of self-compatibility with climax at time of mid-bloom.

It was readily recognized that the self-compatibility of such plants was most strong during the period of mid-bloom, and that previous to and following this period there was complete self-incompatibility. A highly self-compatible plant grown in isolation and carefully self-pollinated from day to day appeared at the end of the fruiting period, as shown in figs. 6 and 7. Repeated tests by crossings showed that in these, as in the case of the self-incompatible

plants, the flowers that opened normally during the time of self-incompatibility were functional in compatible crosses. The results of a test of this sort are shown in fig. 5. The cyclic development of self-compatibility with its coordination among the various branches of an individual according to time of bloom is shown in figs. 2 and 3.

There is evidence from other species (SIRKS 10) that various grades of cross-compatibility may exist between the individuals of the same race or species, that the group relations may be variable in different cultures of the same species or race (EAST and PARK 4), and that in general cross-incompatibilities appear with much the same irregularity in heredity and in expression as do self-incompatibilities.

The writer's studies with these plants have been chiefly concerned with self-compatibility. In the species of *Brassica* studied the cross-relations have not been studied sufficiently to state with certainty whether the grades of cross-incompatibility undergo cyclic changes like those of self-incompatibility, but perhaps it may be assumed that certain of the weaker grades of cross-incompatibility do thus operate.

### Heredity of mid-bloom self-compatibility in pedigreed lines of descent

In the first or "parent" series grown of both *Brassica pekinensis* and *B. chinensis*, of a total of 253 plants there were 21 plants that produced viable seeds to self-pollination during the period of mid-bloom. From such seeds pedigreed progenies were grown through two generations, to test the inheritance of self-compatibility and to determine the result of repeated selection for this character. A summary of the records for the various series and families grown to date is presented in table I. In these records the first series of plants grown are given arbitrary numbers. The number of a series with that of the self-compatible plant used as a seed parent is employed in designating the series of succeeding generations. Thus the line of descent and the relationship of the various series of sister plants are fully indicated.

In one series of the selfed $F_1$ generation of *B. pekinensis* (series 1–2) comprising 88 plants, 24 were strongly self-compatible. In

## TABLE I

RECORDS OF SELF-COMPATIBILITY FOR FAMILIES OF *Brassica pekinensis*, OF *B. chinensis*, AND OF HYBRIDS BETWEEN THESE SPECIES

| ANCESTRY, GENERATION, AND SELF-COMPATIBILITY OF PARENT | RECORD FOR PROGENY | | | | |
|---|---|---|---|---|---|
| | Total number of plants | Number self-incompatible | Self-compatible | | |
| | | | Feeble | Medium | Strong |
| Brassica pekinensis | | | | | |
| P series 1, seeds of S.P.I. no. 44892 | 9 | 7 | 0 | 1 | 1 |
| P series 2, seeds of S.P.I. no. 44935 | 10 | 6 | 2 | 1 | 1 |
| P series 3, seeds of S.P.I. no. 44291 | 20 | 19 | 0 | 1 | 0 |
| P series 4, seeds of S.P.I. no. 44312 | 12 | 9 | 1 | 0 | 2 |
| P series 5, seeds of S.P.I. no. 44292 | 8 | 8 | 0 | 0 | 0 |
| P series 34, seeds of S.P.I. no. 38783 | 114 | 67 | 45 | 2 | 0 |
| P series 15, seeds of S.P.I. no. 45187 | 61 | 55 | 5 | 1 | 0 |
| $F_1$ series 1–2, parent strongly self-compatible | 88 | 25 | 19 | 20 | 24 |
| $F_1$ series 2–1, parent strongly self-compatible | 7 | 7 | 0 | 0 | 0 |
| $F_1$ series 3–1, parent medium self-compatible | 80 | 43 | 27 | 7 | 3 |
| $F_2$ series 1–2–9, parent strongly self-compatible | 36 | 5 | 19 | 9 | 3 |
| $F_2$ series 1–2–18, parent strongly self-compatible | 133 | 14 | 99 | 18 | 2 |
| $F_2$ series 1–2–29, parent strongly self-compatible | 46 | 24 | 21 | 1 | 0 |
| $F_2$ series 1–2–38, parent strongly self-compatible | 60 | 1 | 43 | 15 | 1 |
| $F_2$ series 3–1–1, parent strongly self-compatible | 19 | 15 | 2 | 2 | 0 |
| $F_2$ series 3–1–9, parent strongly self-compatible | 16 | 10 | 6 | 0 | 0 |
| $F_2$ series 3–1–32, parent strongly self-compatible | 18 | 12 | 6 | 0 | 0 |
| Brassica chinensis | | | | | |
| P series 8 | 19 | 4 | 4 | 8 | 3 |
| $F_1$ series 8–1, parent strongly self-compatible | 111 | 42 | 56 | 12 | 1 |
| $F_1$ series 8–5, parent medium self-compatible | 48 | 43 | 3 | 2 | 0 |
| $F_1$ series 8–6, parent strongly self-compatible | 57 | 28 | 26 | 2 | 1 |
| $F_1$ series 8–15, parent strongly self-compatible | 122 | 40 | 74 | 7 | 1 |
| $F_2$ series 8–1–13, parent strongly self-compatible | 13 | 7 | 5 | 1 | 0 |
| $F_2$ series 8–5–32, parent medium self-compatible | 18 | 7 | 10 | 1 | 0 |
| $F_2$ series 8–5–39, parent medium self-compatible | 9 | 7 | 1 | 1 | 0 |
| $F_2$ series 8–15–5, parent strongly self-compatible | 48 | 30 | 16 | 2 | 0 |
| $F_2$ series 8–1, no. 39×8–1 no. 32 (medium×medium) | 30 | 23 | 7 | 0 | 0 |
| $F_2$ series 8–5, no. 39×8–5 no. 41 (medium×self-sterile) | 32 | 15 | 17 | 0 | 0 |
| $F_2$ series 8–5, no. 30×8–5 no. 17 (both self-sterile) | 16 | 15 | 1 | 0 | 0 |
| $F_2$ series 8–5, no. 27×8–5 no. 32 (self-sterile×medium) | 8 | 7 | 0 | 1 | 0 |
| Brassica chinensis×B. pekinensis | | | | | |
| $F_1$ 8–5, no. 23×2 no. 3 (both self-incompatible) | 19 | 19 | 0 | 0 | 0 |
| $F_1$ 8–5, no. 19×3 no. 16 (both self-incompatible) | 34 | 27 | 5 | 2 | 0 |
| $F_1$ 8–5, no. 18×3–1 no. 63 (medium×self-sterile) | 50 | 12 | 14 | 19 | 5 |

the next generation of this family, the progeny of four strongly self-compatible plants, 275 plants were grown. Of these only 44 were completely self-incompatible. There were, however, only 6 plants as highly self-compatible as the immediate seed parents. The majority of the plants (182 in number) were feebly self-compatible and did not produce any viable seeds to selfing. This family, however, was somewhat more highly self-compatible than was the family derived from plant no. 1 of series 3, in the second generation of which only 2 plants out of 53 produced viable seeds to selfing.

Selection for the highest grades of self-compatibility in *B. chinensis* was also carried through the second generation. In the $F_1$ generation, 26 out of 338 plants produced viable seeds to selfing. In the $F_2$, 5 out of 88 plants produced such seeds. The proportion of self-compatible plants was low and remained about the same, not being appreciably increased or decreased in the second generation. No plants classed as highly self-compatible were found in the $F_2$, but this may have been due to the proportionally smaller number of plants grown in this generation.

Four series comprising 86 plants were grown from seeds obtained by crossing certain plants of the $F_1$. Of these, 25 were feebly self-compatible and one plant produced viable seeds. The $F_1$ hybrids between the two species exhibited the three types of sterility characteristic of the parent species. There was no indication of a general impotence of both sex organs (pistils and stamens) such as often results from hybridity. During the time when flowers opened normally, branches left to open pollination produced pods and viable seeds, and about 100 plants of this generation grown in the field and left to open cross-pollination produced pods in abundance.

As to mid-bloom self-compatibility, the $F_1$ hybrids were like the pure bred parents. Relatively few were highly self-compatible. In one series, derived from crossing a plant of a medium grade self-compatibility and one completely self-incompatible, of 50 plants, 12 were fully self-incompatible, 14 were feebly self-compatible, 19 were self-compatible of medium grade, and 5 were

highly self-compatible. Two series were grown from parents that were self-incompatible. In one of these all of the 19 progeny were self-incompatible; in the other series of 34 plants 27 were fully self-incompatible, 5 were feebly self-compatible, and 2 were self-compatible of medium grade during the period of mid-bloom.

SUMMARY.—The results obtained in these various pedigreed cultures show that self-compatibility is a character which is not directly hereditary. Self-compatibility occurs sporadically in a few members of these prevailing self-incompatible species. This character does not breed true. Selection for self-compatibility does not immediately lead to the establishment of self-compatible races. Neither is self-compatibility nor self-incompatibility dominant in crosses. There is some indication, however, that certain races may be secured in which the mode of distribution in respect to self-compatibility is higher than in others.

## Discussion and conclusion

The strains of *Brassica pekinensis* and *B. chinensis* studied were previously selected and bred for excessive leafy growth rather than for fruit and seed production, yet they are reproduced exclusively by seeds. The vegetative vigor is not in the least utilized in the development of parts which may propagate the plants vegetatively. In their habit of growth and bloom, the stage of sexual reproduction in these plants quickly follows a period of remarkably vigorous vegetative development, hence these species are favorable material in which to study the correlative relations of the asexual or the vegetative phase to the sexual or reproductive (by seeds) phase in the complete life cycle.

The two types of sterility, impotence (including flower abortion and arrested development), and proliferation, or the destruction of a pistil by vegetative growth, as they occur in *B. pekinensis* and *B. chinensis*, are both phenomena associated with the formation of floral organs. The other type of sterility, physiological incompatibility or relative sterility which is present, is concerned with the physiological inter-relations of the sex organs in the various processes of fertilization.

These three types of sterility develop and operate in these two species and in their hybrids in intimate correlation with the cyclic

alternation of vegetative and reproductive vigor. Flower abortion occurs normally as a transitional stage between the formation of green leaves and the production of functional sporophylls. Those plants which exhibit flower abortion are not able to pass directly from producing green leaves or leaves with branches at the nodes to the production of flowers, and flower abortion occurs as a transitional stage. The abortion of flowers appears in the phase where vegetative vigor is waning, but before reproductive vigor is fully in evidence. There is also a marked agreement among the various branches of a plant as to the grade of development reached at any one date of blooming (figs. 1–3), which indicates a definite relation between the condition causing flower abortion (and also normal flower formation) and a condition of the plant as a whole. These phenomena, therefore, have many aspects characteristic of physiological correlation.

The arrested development of flowers at the ends of branches after a period of vigorous blooming of the plant is obviously due to an extreme waning of vigor and the approaching death of the plant as a whole, and of course is a phenomenon prevalent in all sorts of plants. Axial proliferation from the pistils is to be considered as a resumption of vegetative growth after the differentiation of the pistils has been accomplished.

Turning to the functional relations of the sex organs in these two species of *Brassica*, at least to the compatibility in self-fertilization, it is seen that they also exhibit a periodicity on their occurrence which forms a very definite cycle. A total of 718 plants that were self-compatible to some degree have now been observed in these two species and in hybrids between them. With the exception of a few individuals in which pods developed irregularly, the maximum of self-compatibility was reached during the mid-bloom of the plant (figs. 2, 3, 5–7). Previous to and following this period, the self-compatibility grades into complete self-incompatibility or into a much weaker grade of self-compatibility. Furthermore, the climax of self-compatibility is remarkably coordinated among the different branches according to the time of blooming quite as is the earlier development of flower abortion.

The remarkably uniform development of self-compatibility during the time of mid-bloom in *Brassica chinensis*, *B. pekinensis*,

and hybrids between them, is convincing evidence that the functions of fertilization are here operating in a cycle of intensities. The period of mid-bloom may be considered as the time when conditions are most favorable for fertilization. The cross-fertilizations which are highly effective both previous to and following the maximum for self-compatibility are hence to be considered as indicating a different and possibly a stronger grade of sexual relation. It seems conclusive that, judged by the functional relations in fertilization, the physiological properties of the sex organs in these plants vary in a rather definite cycle.

It is clear that self-compatibility as contrasted with certain grades of cross-compatibility in these species of *Brassica* is limited to a specific period following the transition from vegetative to reproductive activity and limited by the waning senility of the plant as a whole. Self-compatibility appears coincidently with the climax of the reproductive activity.

Sexual reproduction itself is generally characterized as a phenomenon of maturity (COULTER 3). The differentiations of sex as indicated by anatomical features and by the physiological compatibilities are perhaps to be considered as a smaller cycle operating within the larger alternation of vegetative and reproductive phases and subject to the same biogenetic regulation.

In the flowering plants especially, there is great diversity among species in the relative development of their vegetative and reproductive habits and in the inter-relations between these two phases. Perhaps the most universal of the biogenetic conditions incident to the transition from the vegetative to the reproductive phase is that change in nutrition which leads to the accumulation of carbon compounds. This is an internal condition that arises in the plant as a whole in the course of maturity, in contrast with relative excess of nitrogenous material that is characteristic of the vegetative stage. The decided influence of nutritive relations in regulating development and in influencing fruitfulness has recently been discussed by KRAUS and KRAYBILL (7), who have emphasized the fact that a well-balanced development, especially in regard to fruitfulness of fruit-bearing plants, is associated with a proper balance between nitrogen and carbohydrate metabolism.

It is not to be considered, however, that a single simple change in nutrition is the sole biogenetic factor regulating the appearance of maturity and its attending morphogenesis of flowers. In flowering plants, such as the species of *Brassica* whose sterilities are reported in this paper, there is progressive differentiation of parts in reference to metabolic activities which is most obvious in respect to the manufacture, distribution, and consumption of food. It has been shown that there are also special stimulating and inhibiting influences which in a decided manner regulate and correlate development. That these influences may be substantive and special (but metabolic) and different from food materials was postulated by SACHS (8) in one of the latest of his papers; that some influences are stimulative and correlative in the sense of nervelike impulses or even electrical stimuli have repeatedly been shown in studies of the nature of transmission and excitation in phenomena of dominance and control in correlative growth and development (CHILD 1).

It is to be noted that the complete life cycle of flowering plants involves two periods of vegetative vigor and maturity; one for the sporophyte and one for the gametophyte. The former culminates in the production of spores and the latter in the production of gametes. The generations are antithetic. In its length of life, vigor of vegetative growth, and reproductive power (number of gametes), the gametophytic phase has become relatively weak and highly specialized. In the sporophyte great vegetative vigor is correlated with great reproductive vigor in the production of spores (which are, however, in themselves asexual) and in the nurture of the gametophyte and the embryo. Sex differentiation in the great group of flowering plants has been pushed back during the progress of evolution into the sporophytic stage of the entire cycle, and here sexuality now culminates in seed formation in which the nutrition of the embryo is a most important factor. Sexual reproduction in these higher plants has become more and more inter-related with the vegetative phase of the sporophyte and subject to its internal and biogenetic regulation.

The decided influence of such regulation is seen in the fact that in the great group of hermaphrodite plants, the whole trend of the

morphological and physiological differentiations constituting sexuality is initiated in the morphogenesis of flowers. The cells of pistils and stamens are not only alike in their preformed genetic composition, but they are identical in this particular with the cells that entered into the preceding vegetative structures. CORRENS (2) has noted that the regeneration from sister cells of the egg and sperm (the archegonial and antheridial cells) in certain monoecious mosses shows that, at least in hermaphrodites and monoecious plants, maleness and femaleness are carried equally by both male and female gametes. The male gametophytes and their most highly specialized male cells are male only because of a temporary suppression of femaleness. Likewise the femaleness of egg cells is a temporary and one-sided expression of cells carrying both sex potencies. The various expressions of maleness and femaleness even in the sex generation, at least in hermaphrodite plants, according to CORRENS, are "phenotypic" or biogenetic expressions independent of any qualitative differentiation in the component units of the germ plasm. The expressions of the so-called factors for sex or the so-called inhibitors of one or the other sex are hence independent of corresponding differentiations in germ plasm which may have arisen during sporogenesis. The expression of sex, therefore, is on the same basis as are the somatic differentiations that arise among the various parts of the individual. It hence becomes a most fundamental biological problem to consider and to determine as far as possible what conditions determine these differences in the level of the so-called "physiological gradient."

Maturity, with its transition from the vegetative to the reproductive phase, whether giving homologous or antithetic alternation or a continuation of either, occurs in cycle after cycle with remarkable uniformity. This emphasizes the phylogenetic or hereditary aspect of particular phases of the development. One may assume a "gene" or a "factor" for maturity, and assume that it is gradually awakened from a dormant condition to the exercise of its influence at a particular time and in a particular group of cells. One may further assume that the loss of such a gene would throw a line of progeny into a condition of perpetual immaturity, so that flowers or other reproductive organs could never be formed. The evidence

is decidedly against such a view. The loss of maturity, as seen especially in the complete failure of flower formation, has very universally been shown to be due to the indirect influence of such external factors as light, heat, and nutrition on the metabolism and attending correlations in the organism (see numerous papers by MÖBIUS, VÖCHTING, KLEBS, SACHS, and GOEBEL, and recent papers by GARNER and ALLARD **5** and **6**, and by SETCHELL **9**).

That species or strains showing flower abortion and physiological incompatibility are different genetically from others that do not show such sterilities is obvious. That these types of sterility are more completely hereditary in some species than in others is clear. That these characteristics are not definitely and directly represented as such in the germ plasm by hereditary units is very evident from the results of genetical studies. Self-compatibility and self-incompatibility especially are not found to be alternative conditions in tests by crossing or in line breeding; the heredity is decidedly irregular and sporadic even when compatibilities are not cyclic in their appearance as they are in *Brassica chinensis* and *B. pekinensis*.

The various types of sterility seen in these species of *Brassica* decidedly indicate a mutually limiting relationship between vegetative and reproductive vigor. Their irregular inheritance, their appearance at definite periods in the cycle of development of the plant as a whole, and especially the cyclic manifestation of self-compatibility, indicate that the morphological and physiological differentiations of sex are regulated and determined by those internal and biogenetic processes which in general determine the cycle of growth, development, and maturity in the life of the individual.

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## LITERATURE CITED

1. CHILD, C. M., Certain aspects of the problem of physiological correlation. Amer. Jour. Bot. **8**:286–295. 1921.
2. CORRENS, C., Die geschlechtliche Tendenz der Keimzellen gemischtgeschlechtiger Pflanzen. Zeitschr. Bot. **12**:49–60. 1920.
3. COULTER, JOHN M., Evolution of sex in plants. Chicago. 1914.

4. EAST, E. M., and PARK, J. B., Studies on self-sterility. I. The behavior of self-sterile plants. Genetics **2**:505–609. 1917.
5. GARNER, W. W., and ALLARD, H. A., Effect of the relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agric. Research **18**:553–606. 1920.
6. ———, Flowering and fruiting of plants as controlled by the length of day. Year Book U.S. Dept. Agric. 1920 (pp. 377–400).
7. KRAUS, E. J., and KRAYBILL, H. R., Vegetation and reproduction with special reference to the tomato. Oregon Exp. Sta. Bull. 149. 1918.
8. SACHS, J. VON, Physiologische Notizen. VII. Über Wachsthumperioden und Bildungsreize. Flora **77**:217–253.
9. SETCHELL, W. A., Geographical distribution of the marine spermaphytes. Bull. Torr. Bot. Club **47**:563–579. 1920.
10. SIRKS, M. J., Stérilité, auto-incompatibilité, et differenciation sexuelle physiologique. Arch. Néerland. Sci. Exactes et Naturelles, B. **3**:205–234. 1917.
11. STOUT, A. B., Further experimental studies on self-incompatibility in hermaphrodite plants. Jour. Genetics **9**:85–129. 1920.
12. ———, Self- and cross-pollinations in *Cichorium Intybus* with reference to sterility. Mem. N.Y. Bot. Gard. **6**:333–454. 1916.

# THE PELTATE PEPEROMIAS OF NORTH AMERICA[1]

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(WITH PLATES I–IV)

A herbaceous pepper from Santo Domingo, with large slightly peltate leaves, was called *Piper maculosum* by LINNAEUS in 1753, the year conventionally agreed upon as the starting point in phanerogamic nomenclature. This species was transferred to *Peperomia* by the elder HOOKER in 1825. When RUIZ and PAVON established the genus *Peperomia* in 1794, they included in it three Peruvian species with peltate leaves; one of these they named *P. umbilicata* and one *P. variegata*. In 1804 VAHL described, as *Piper hernandifolium*, a fifth species, from the West Indies, with such foliage. DIETRICH recognized this as a *Peperomia* in 1831. Another South American *Peperomia* was described in 1815 by HUMBOLDT, BONPLAND, and KUNTH, who also found in Mexico what they took for the *Peperomia umbilicata* of RUIZ and PAVON.

Following these determinations, most of the Mexican specimens with centrally peltate foliage have been called *P. umbilicata;* but MARTENS and GALEOTTI differentiated a close counterpart of *P. umbilicata* in 1843, as well as a diminutive species with barely peltate leaves. On the latter, before the Belgian botanists had secured printing of their account of GALEOTTI'S numerous discoveries in the Mexican flora, MIQUEL, who was engaged on a monographic study of the Piperaceae, based the name *Tildenia mexicana*, and transferred it to *Peperomia* under the same specific name in 1843 in his classic monograph of the Piperaceae, where their other peltate species appears as *P. monticola*, and which also added the Brazilian peltate species *P. arifolia* now so much cultivated in a silvery-striped variety. A Guatemalan species rather closely comparable in some respects with the original *P. umbilicata* was named *P. claytonioides* in 1847 by KUNTH, to whom are com-

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monly attributed the names used in the joint publication of HUMBOLDT, BONPLAND, and KUNTH.

As a result of studies preliminary to his own monograph of the Piperaceae, in 1866 DE CANDOLLE added two South American species to the *P. umbilicata* group, as well as one, *P. ovato-peltata*, questionably based on both Mexican and Costa Rican material and scarcely distinguishable today, and a caulescent subpeltate species, *P. cordulata*, from Panama. Shortly after the publication of DE CANDOLLE's monograph in 1869, he gave publicity to a diminutive Mexican species, *P. fugax*, which LIEBMANN had discovered and named in manuscript, in addition to two scarcely differentiable larger peltate species, *P. Muelleri* and *P. Bourgeaui*, from eastern Mexico. Slightly antedating the publication of these, BAKER described another, *P. puberula*, very closely related to them, from Gautemalan plants cultivated in England.

It was not until 1887 that another addition was made to the *P. umbilicata* group, when WATSON distinguished in what he called *P. gracillima* a west Mexican counterpart of the original Peruvian species and its representatives in eastern Mexico and Guatemala. Four years later, DE CANDOLLE described *P. scutellata*, of Costa Rica, and in the course of the following decade further named an additional peltate species, *P. macrandra* from Mexico; and from Central America added five others, *P. peltata*, *P. sciaphila*, *P. Tuerckheimii*, *P. tecticola*, and *P. podocarpa;* and in 1902 *P. Bakerii* was described by him from Cuba.

At the end of the century all of the available material was gone over critically by DAHLSTEDT in an exhaustive revision; but an even more fruitful comparative study of the corm-producing group, centering about *P. umbilicata*, was made nearly a decade later by A. W. HILL, whose Andean field observations and seedling studies of the geophilous species led to a very satisfactory morphological distinction between North American and South American groups, centering respectively about *P. umbilicata*, and the Mexican forms that had been mistaken for or too closely connected with that Peruvian plant. In addition to describing several new peltate species from the southern continent, he differentiated under the name *P. campylotropa* what appeared to be the most frequently

encountered northern surrogate of the true *P. umbilicata*, and added a new Guatemalan species, *P. bracteata*.

The purpose of the present paper is to outline succinctly the result of a preliminary study of the peltate-leaved species of *Peperomia* of North America, inclusive of the West Indies, based chiefly on the extensive collections of the United States National Herbarium and the New York Botanical Garden. For the privilege of examining these, I am greatly indebted to Mr. MAXON and Dr. BRITTON. No effort is made here to give full descriptions or citations; but the admitted species are keyed apart sufficiently for their present characterization, and reference is made to all publications affecting their nomenclature.

Although they agree in possessing more or less strikingly peltate foliage, the plants here accounted for constitute four natural groups of species, of which the first three are interrelated, while the fourth has little in common with the others except that it falls within the generic limits of *Peperomia* as these are now drawn. Each of the first two groups is subdivisible into minor groups on floral as well as vegetative characters. These distinctions are sufficiently evident from the synopsis without separate discussion. Except for the very distinct fourth group, Hernandifoliae, all are continental.

### SYNOPSIS OF GROUPS

Acaulescent; pistil not in a pit; stigma apical
- From a round or lens-shaped corm; glabrous ..... CAMPYLOTROPAE
- Subrhizomatous; glabrous; diminutive ..... MEXICANAE
- Subrhizomatous; glabrous; rather large ..... MACRANDRAE
- Substoloniferous; pubescent; diminutive ..... TUERCKHEIMIEAE

Shortly caulescent; pistil not in a pit; stigma subapical
- Small and delicate; somewhat pubescent ..... FUGACES
- Moderately large ..... ARIFOLIAE

Repent; moderately large; pistil not in a pit; stigma apical .. CORDULATIFORMES

Repent; rather large; pistil in a pit, beaked; stigma at base of beak ..... HERNANDIFOLIAE

### CAMPYLOTROPAE

Rather small, acaulescent from a smooth corm, glabrous; leaves peltate near the middle or well above the base; spikes usually very

slender and loosely flowered; bracts oblong-ovate, pointed; pistil not immersed in the rachis; stigma apical.

Leaves orbicular, rarely subacuminate; scapes unbranched
  Filaments scarcely protruding beyond the bract; berries essentially sessile
    Stigma sessile
      Ovary blunt
        Berries ellipsoid ..... *P. monticola*
        Berries globose ..... *P. Painteri*
      Ovary subacute ..... *P. astyla*
    Stigma on a more or less evident style
      Style or stylopodium broadly conic ..... *P. Parryana*
      Style slender-conic ..... *P. tenuimucronata*
      Style rather abruptly cylindric ..... *P. campylotropa*
  Filaments conspicuously exserted
    Anther cells at length divergent ..... *P. schizandra*
    Anther cells not divergent
      Berries flask-shaped, sessile ..... *P. amphoricarpa*
      Berries ovoid, substipitate ..... *P. gracillima*
Leaves subrhombic-orbicular; scapes unbranched ..... *P. bracteata*
Leaves orbicular-acuminate; scapes often branched;
    berries sessile
  Berries flask-shaped with tapering style ..... *P. schizostachya*
  Berries subglobose with abrupt style ..... *P. claytonioides*
Leaves ovate
  Scapes often branched; berries sessile
    Scapes characteristically branched ..... *P. sciaphila*
    Many scapes unbranched ..... *P. ovato-peltata*
  Scapes unbranched; berries stipitate, with slender style ..... *P. peltata*

PEPEROMIA MONTICOLA Miquel, Syst. Piper. 71. 1843.—*Piper* (§*Peperomia*) *hydrocotylifolium* Martens and Galeotti, Bull. Acad. Bruxelles **10**:129. 1843.—*?Peperomia umbilicata macrophylla* C.DC. in DC. Prodr. **16**[1]:394. 1869.—Acaulescent; glabrous throughout; leaves round, centrally peltate, 3.5–5.5 cm. in diameter; berries sessile, ellipsoid; stigma sessile at the apex.

Southern Cordillera of Mexico, the type from near Tehuacan, Puebl. (*Galeotti* 6023, which is also the type of *Piper hydrocotylifolium*).

As with *P. mexicana*, this was distinguished and described by its discoverer, but antedated in publication by another, as was true also of two of GALEOTTI'S Mexican oaks.

**Peperomia Painteri,** n. sp.—*?Peperomia umbilicata subacutifolia* C.DC. in DC. Prodr. **16**[1]:394. 1869.—Aspect and general

characters of the preceding; leaves 1.5–2 cm. in diameter; berries globose; stigma sessile at the apex.—Fig. 5.

Table-land and adjacent Cordillera of Mexico, the type from Ixmiquilpan, Hidalgo (*Rose, Painter,* and *Rose* 8966).

**Peperomia astyla,** n. sp.—Aspect of the preceding; leaves 1.5–2.5 cm. in diameter, sometimes blunt-acuminate; ovary ovoid-flask-shaped, subacute; stigma apical.—Fig. 4.

Western Sierra Madre of Mexico, the type from Lake Patzcuaro, Michoacan (*Pringle* 4124).

**Peperomia Parryana,** n. sp.—Aspect of the preceding but the scapes sometimes 20 cm. long; ovary round-ovoid, tapering into a short broadly conic disk or style; stigma apical.—Fig. 7.

Eastern Sierra Madre and adjacent table-land of Mexico, the type from about San Luis Potosi, S.L.P. (*Parry* and *Palmer* 802).

With more filiform spikes and larger broadly conic style, it is var. **borealis,** n. var.

Type from La Silla, Monterrey, N.L. (*Pringle* 3018).

**Peperomia tenuimucronata,** n. sp.—Aspect of the preceding species; ovary flask-shaped, slenderly attenuate; stigma apical.—Fig. 12.

Western Sierra Madre of Mexico, and Cape region of Baja California, the type from near Santa Teresa, Tepic (*Rose* 3432).

PEPEROMIA CAMPYLOTROPA Hill, Ann. Botany **21**:156. 1907.—Aspect of the preceding species and taken as typical of the group which they constitute; leaves 1.5–3.5 cm. in diameter; berries round-ovoid, with a short cylindric style; stigma apical.—Fig. 10.

Mexican table-land and adjacent mountains; taken to be *P. umbilicata* HBK. (not RUIZ and PAVON), the type of which was from Santa Rosa de la Sierra (*Humboldt*).

**Peperomia schizandra,** n. sp.—Aspect of the preceding; leaves 4–5.5 cm. in diameter; stamens somewhat exserted, their anther cells at length widely spreading; berries ovoid, somewhat acuminately pointed; stigma apical.—Fig. 1.

Western Sierra Madre of Mexico, the type from Bolaños, Jal. (*Rose* 2883).

**Peperomia amphoricarpa,** n. sp.—Aspect of the preceding; stamens exserted; ovary oblong; berries ovoid-flask-shaped, gradually attenuate; stigma apical, for a time white-fimbriate.—Fig. 11.

Southern Cordillera of Mexico, the type from the Cerro San Felipe, Oax. (*Nelson* 1139). Presumably it was this which MARTENS and GALEOTTI took for *P. umbilicata.*

PEPEROMIA GRACILLIMA S. Wats.—*Peperomia gracillima* S. Wats., Proc. Amer. Acad. **22**:448. 1887.—Aspect of the preceding; leaves 1.5–2 or even 4 cm. in diameter; filaments exserted beyond the bract; ovary ovoid, (?normally) stipitately contracted, with a stout style; stigma apical.—Fig. 6.

Western Sierra Madre of Mexico, the type from the Rio Blanco, near Guadalajara, Jalisco (*Palmer* 585).

PEPEROMIA BRACTEATA Hill, Ann. Botany **21**:155. 1907.—Aspect of the preceding; leaves subrhombic-orbicular, slightly blunt-pointed, 2–3 cm. in diameter; berries subfusiform-globose, with a thick terminal disk or stylopodium; stigma apical.

Guatemala, the type from Sactos, Huehuetenango (*Seler* 2743).

**Peperomia schizostachya,** n. sp.—Aspect of the preceding; leaves subangularly ovate, more or less cuspidate or deltoid-pointed, 2×2.5–5×7 cm.; scapes simple or forked; berries flask-shaped, attenuate; stigma apical.—Fig. 2.

Costa Rica, the type from the Rio Virilla, near San Juan (*Tonduz* 10106=7273).

PEPEROMIA CLAYTONIOIDES Kunth, Index Sem. Hort. Berol. **1847**:11.—Aspect of the preceding; leaves ovate or round-ovate, more or less acuminate, 2–4 cm. in diameter; spikes characteristically 2 or 3 at end of the branching scape; berries subglobose-cylindric, with an abrupt style; stigma apical.

Guatemala, the type cultivated from an unrecorded Guatemalan locality.

With scapes much longer than the leaves, and bearing 4–6 alternate branches near the end, it is var. **longiscapa** C.DC., MS. n. var.—Fig. 13.

Guatemala, the type (*Bernhardi*) from an unspecified locality.

With scapes scarcely surpassing the leaves, bearing 4–6 subapical spikes scarcely 3 cm. long, it is var. **pinulana** C.DC., MS. n. var. (*P. pinulana* C.DC., Bot. Jahrb. **10**:289. 1889).

Guatemala, the type from Pinula, near Xalapa (*Lehmann* 1693).

PEPEROMIA SCIAPHILA C.DC., An. Inst. Fis.-Geogr. Costa Rica **9**:175. (1898?).—*?Peperomia ovato-peltata* Auct., as to Costa Rica.—Acaulescent; leaves broadly ovate, blunt-acuminate, rounded at base, peltate below the middle; spikes scarcely 2 cm. long, 2–7 nearly sessile at end of a filiform scape surpassing the leaves; ovary ovoid, subacute; stigma apical.—Fig. 14.

Costa Rica, the type from the Rio Virilla near San Juan (*Tonduz* 9630).

PEPEROMIA OVATO-PELTATA C.DC., Jour. Botany **4**:132. 1866.—Aspect of the preceding; leaves broadly ovate, acuminate, peltate one-third above the rounded or subcordate base; spikes solitary or 2 or 3 near the end of a filiform scape equaling or surpassing the leaves; ovary round-ovoid, contracted into an equilong fleshy style; stigma apical.

A problematic species, perhaps representing a depauperate form of the preceding and if so to replace it in name. Two specimens (New Spain, *Pavon;* Costa Rica, *Hoffmann* 521) are mentioned with the original description, but both are questioned there.

PEPEROMIA PELTATA C.DC., Ann. Conserv. and Jard. Bot. Genève. **2**:277. 1898.—*P. pedicellata* Dahlst., Svensk. Vet.-Akad. Handl. **32²**:35. 1900.—*P. ovato-peltata* Auct., as to Guatemala.—*?P. mexicana* Auct., as to Guatemala.—Acaulescent; leaves broadly ovate, subacuminate, truncately cordate, peltate toward the base, 2×3–3×4 or 5 cm.; scape unbranched; berries long and slender, tapering into an extremely slender stipe; stigma apical.—Fig. 15.

Guatemala, the type from Santa Rosa (*J. D. Smith* 3829, which is also the type collection of *P. pedicellata*).

## MEXICANAE

Diminutive, subacaulescent from a small, finally branching rhizome; glabrous; leaves peltate at the very base; peduncles

unbranched; spikes filiform, loosely flowered; bracts ovate, pointed; pistil not immersed in the rachis; stigma apical.

Leaves ovate-oblong, style slender.....*P. mexicana*

PEPEROMIA MEXICANA (Miq.) Miquel, Syst. Piper. 75. 1843.—*Tildenia mexicana* Miquel, Diar. Inst. Reg. Nederl. 83. 1842.—*Piper* (§*Peperomia*) *parvulum* Martens and Galeotti, Bull. Acad. Roy. Bruxelles **10**:130. 1843.—*Peperomia Galeottiana* Hooker, Icon. Plant. **4**. *pl. 327*.—Essentially acaulescent, from a short rhizome, very small, glabrous throughout; leaves ovate and obtuse or characteristically lance-ovate or elliptic-ovate and attenuate, peltate extremely close to the base, 8×12–10×25–30 mm.; spikes solitary at end of filiform scapes twice as long as the petioles; berries oblong, pointed; stigma apical.—Fig. 3.

Eastern Sierra Madre of Mexico, the type from Mirador, Vera Cruz (*Galeotti* 7111, which is also the type of *Piper parvulum*).

MACRANDRAE

Moderately large, subacaulescent from a short branching rhizome, glabrous; leaves peltate below the middle; scapes unbranched; spikes loosely flowered; bracts ovate, pointed; pistil not immersed in the rachis, stigma apical.

Leaves elongated-ovate; berries oblong.....*P. macrandra*

PEPEROMIA MACRANDRA C.DC., Ann. Conserv. and Jard. Bot. Genève **2**:276. 1898.—Essentially acaulescent, from a short thick polycephalous rhizome, glabrous throughout; leaves ovate, acuminate, peltate toward the base, 2.5×4–4.5×7 cm.; spikes solitary at end of scapes rather surpassing the petioles; filaments exserted; berries ellipsoid-oblong, (teratologically?) gradually tapering into an equilong style; stigma apical.

Southern Cordillera, Mexico, the type from San Felipe, Oax. (*Pringle* 4654).

A large form, presumably from the same geographic region, with round-ovate leaves as much as 8×10 cm. and shorter beak on the fruit, is var. **ampla,** n. var.

Type, without other data, occurring in the United States National Herbarium as *Pringle* 13282.—Fig. 8.

### Tuerckheimieae

Diminutive, subacaulescent from a short rhizome, sparsely villous; leaves peltate toward the base; peduncles unbranched; spikes filiform, loosely flowered; bracts round-ovate, scarcely pointed; pistil not immersed in the rachis; stigma apical.

Leaves ovate, small ..... *P. Tuerckheimii*

Peperomia Tuerckheimii C.DC., Ann. Conserv. and Jard. Bot. Genève **2**:279. 1898.—Nearly acaulescent, small, dingy-villous; leaves alternate, ovate, acute, peltate toward the base, 2×2.5 cm. with equilong petiole; spikes axillary, filiform, short (20–40 mm.); berries ovoid, subacute; stigma apical.—Fig. 9.

Guatemala, the type from Pansamala (*von Tuerckheim* 433).

### Fugaces

Diminutive, caulescent, slightly pubescent; leaves peltate toward the base; peduncles unbranched; spikes filiform; pistil not immersed in the rachis; stigma subapical.

Leaves ovate; spikes pubescent ..... *P. fugax*

Peperomia fugax Liebmann, in C.DC., Linnaea **37**:370. "1871–3."—Shortly caulescent (3 cm. high), locally hairy; leaves alternate, ovate, acute, peltate toward the base, ciliolate, scarcely 10×13 mm., on an even shorter hairy petiole; spikes axillary; ovary ovoid; stigma suboblique.

Eastern Sierra Madre, Mexico, the type from Mirador, Vera Cruz (*Liebmann*).

### Arifoliae

Moderately large, with a usually evident thick erect stem from a rhizome; leaves peltate below the middle; peduncles unbranched; spikes moderately slender and closely flowered; bracts orbicular; pistil not immersed in the rachis; stigma subapical.

Glabrous ..... *P. arifolia*
Pubescent
  Spikes rather thick
    Stigma obliquely subsessile ..... *P. puberula*
    Stigma on a short style ..... *P. Muelleri*
  Spikes scarcely 1 mm. thick ..... *P. tecticola*
  Spikes 1-2 mm. thick ..... *P Killipi*

PEPEROMIA ARIFOLIA Miquel, Syst. Piper. 72. 1843.—Shortly caulescent, succulent, glabrous; leaves alternate, round-ovate, subacute or short-pointed, peltate toward the truncately subcordate base, 5–6×6–9 cm., the petiole nearly as long; spikes terminal, solitary, about 100 mm. long, on nearly equilong peduncles; berries ovoid; stigma essentially sessile at or very near the end.

A Brazilian species, the type cultivated in Europe; common everywhere in conservatories in the nearly acaulescent silver-striped var. *argyreia* (or *P. Saundersii*); reported, doubtless in cultivation, for Bermuda; and represented by a var. **acutifolia** C.DC., n. var., with acute smaller leaves 3.5×5.5 cm., on petioles 7.5 cm. long, cultivated in Switzerland from Costa Rican (?cultivated) material.

PEPEROMIA PUBERULA J. G. Baker, in Saunders, Ref. Bot. **5**. *pl. 302*. 1871.—Shortly caulescent, rather succulent, somewhat velvety; leaves alternate, broadly ovate, subacute or abruptly short-pointed, peltate toward the rounded or subcordate base, 3×4–6×7 cm., the petiole of more or less equal length; spikes terminal and axillary, 50–100 mm. long, on somewhat shorter peduncles; berries obovoid, the subsessile stigma slightly oblique.—Fig. 17.

Guatemala, the type cultivated in England from Alta Vera Paz.

PEPEROMIA MUELLERI C.DC., Linnaea **37**:366. "1871–3."—*Peperomia Bourgeaui* C.DC., Linnaea **37**:370. "1871–3."—Shortly caulescent, rather succulent, gray-pilose; leaves alternate, broadly ovate, more or less acuminate, peltate toward the subcordate base, 4–6×6–7.5 cm., the petiole slightly shorter; spikes terminal and axillary, slender, equaling or surpassing the leaves, the peduncle shorter than the petiole; berries round-ovoid, obliquely short-mucronate, terminated by the stigma.

Eastern Sierra Madre, Mexico, the type from Orizaba, Vera Cruz (*Mueller* 653); that of *P. Bourgeaui* from the Rio Blanco near Orizaba (*Bourgeau* 3230).

PEPEROMIA TECTICOLA C.DC., An. Inst. Fis.-Geogr. Costa Rica **9**:175. (1898?).—Shortly caulescent, rather succulent, loosely short-hairy; leaves alternate, ovate or elongate-ovate, somewhat acuminate, peltate toward the rounded or shallowly subcordate base, 2×4 cm., the petiole about equilong; spikes terminal or

axillary, solitary, 80–120 mm. long, densely flowered, on peduncles about as long as the petioles; bracts round-peltate; berries round-ellipsoid; stigma oblique.

Costa Rica, the type from San José (*Tonduz 7262*, in a roof gutter).

A form with larger leaves 3–3.5×6–7 cm. and spikes fully 150 mm. long, is var. **muricola,** n. var., Costa Rica, the type from San Juan (*Tonduz* 10146, on a wall).—Fig. 16.

**Peperomia Killipi,** n. sp.—Shortly caulescent, rather succulent, glabrate; leaves alternate, round-ovate, somewhat blunt-attenuate, barely subpeltate at the rounded or slightly cordate base, ciliolate, 3–3.5 cm. long and wide, the petiole about equilong; spikes terminal or axillary, solitary, 60 mm. long, densely flowered, on elongated peduncles; bracts round-peltate; berries round-ovoid; stigma oblique.

Panama, the type from Alhajuela, on the Chágres River (*Killip 3218*).

### Cordulatiformes

Moderately large, repent or ascending, rooting from some nodes; leaves in part barely subpeltate at the very base, alternate; spikes solitary, terminal or opposite the leaves, closely flowered; bracts orbicular; pistils not immersed in the rachis; stigma apical.

Glabrous; berries sessile
  Spikes rather thick ..... *P. cordulata*
  Spikes scarcely 1 mm. thick ..... *P. cordulatiformis*
Somewhat hairy; berries stipitate ..... *P. podocarpa*

Peperomia cordulata C.DC., Jour. Botany **4**:137. 1866.—Ascending, glabrous, slender; leaves alternate, round-ovate or ovate, subacute, obscurely subpeltate at the subcordate base, 5.5×7 cm., the petiole about 1 cm. long; spikes terminal, solitary, 150 mm. long; berries ovoid-acute; stigma oblique.

Panama, the type (*Fendler 265*) from an unrecorded locality.

**Peperomia cordulatiformis,** n. sp.—Ascending, glabrous, rather succulent; leaves alternate, round-ovate, bluntly short-acuminate, obscurely subpeltate at the cordate base, 3.5×5–5×6 cm., the petiole about 1 cm. long; spikes opposite the leaves, solitary,

filiform, scarcely 50 mm. long; berries round-ovoid; stigma oblique.—Fig. 19.

Panama, the type from Mamei Hill in the Canal Zone (*Pittier* 3806).

PEPEROMIA PODOCARPA C.DC., An. Inst. Fis.-Geogr. Costa Rica **9**:175. (1898?).—Repent, more or less pilose, delicate, the stem scarcely over 1 mm. thick; leaves alternate, broadly ovate, cuspidate, peltate near the rounded base, 4×6 mm., the petiole shorter than the blade; spikes paired on short axillary or terminal stalks, very slender and short (0.5×15 mm.) and short-peduncled; berries oblong-ellipsoid, slender-stipitate, obtuse.

Costa Rica, the type from El General (*Pittier* 10595).

### HERNANDIFOLIAE[2]

Rather large, repent and rooting from the nodes; leaves variously peltate, alternate; spikes solitary, or paired on a common stalk, closely flowered; bracts orbicular; pistils sessile, immersed in ovoid pits in the rachis, beaked, the stigma at base of the beak and exposed at the level of the rachis; the glutinous berries finally broken loose and extruded at right angles to the contracting rachis.

Usually puberulous, berries subovoid ..... *P. hernandifolia*
Leaves ciliate; berries cylindric ..... *P. Bakerii*
Glabrous
  Leaves round-ovate ..... *P. peltilimba*
  Leaves lance-ovate, barely subpeltate ..... *P. scutellata*

PEPEROMIA HERNANDIFOLIA (Vahl) A. Dietr., Sp. **1**:157. 1831.—*Piper hernandifolium* Vahl, Enum. **1**:344. 1804.—*Peperomia Ponthieui* Miq., Syst. Piper. 186. 1843.—Repent, somewhat succulent, usually puberulous, the stem 2 mm. thick with elongated internodes; leaves alternate, broadly ovate, somewhat obliquely acuminate, rounded at base or subcordate, peltate below the middle, 4–5×6–8 or even 8×12 cm., the petiole 4–10 cm. long; spikes 1 or 2 at end of an axillary 1-bracted stalk 3–4 cm. long, 30–50 mm. long with an equilong peduncle; berries oblong-ovoid,

[2]The Antillean *P. distachya*, representative of a related group of species, sometimes has leaves barely subpeltate.

with a slender flexuous beak; stigma anterior at base of the beak.—Fig. 18.

Through the West Indies (to which the type is ascribed) and reaching Venezuela.

In the Eastern Sierra Madre of Mexico it is represented by an almost entirely glabrescent form, var. **calva,** n. var., the type of which is from Orizaba (*Botteri* 1158).

A Costa Rican form, glabrescent except that the rather large leaves are ciliate, is var. **ciliifera,** n. var., the type from Estrella, Cartago (*Cooper* 5917).

A glabrate Costa Rican form with filiform peduncle is var. **filipes,** n. var., the type from La Palma (*Tonduz* 12539).—Fig. 18, habit.

With even the upper face of the coriaceous, abruptly short-acuminate leaves puberulent, it is var. **cryptocarpa,** n. var., the type from near the Finca Sepacuite, Alta Verapaz, Guatemala (*Cook* and *Griggs* 533).

PEPEROMIA BAKERII C.DC. in Urban, Symbolae Antillanae **5**:296. 1902.—Of the aspect of *P. hernandifolia* and scarcely separable, but with ciliate leaves and more cylindrical slender-beaked berries.

Cuba, the type from Lomas de Taro-Taro, Pinar del Rio (*Baker* 3833).

**Peperomia peltilimba** C.DC., n. sp.—Repent, glabrous, rather thick-stemmed; leaves alternate, round-ovate, sharply acuminate, peltate toward the rounded base, 3.5–5×4–5.5 cm., the petiole scarcely as long as the blade; spikes paired on bracted stalks, relatively thick and short (3×25 mm.); ovary ovoid, obliquely beaked, the stigma anterior on the beak.

Costa Rica, the type from San Ramon (*Brenes* 14178).

PEPEROMIA SCUTELLATA C.DC., Bull. Soc. Roy. Bot. Belg. **30**:230. 1891.—Repent, glabrous, rather slender-stemmed; leaves alternate, lance-ovate, barely subpeltate at the very base, 3.5×7–8 cm., the petiole 4–8 cm. long; spikes paired on a short terminal stalk, shorter than the leaves; berries cylindrical, slender-beaked; stigma anterior on the beak.

Costa Rica, the type from near Division (*Pittier* 3611).

PEPEROMIA MACULOSA (L.) Hook., Exot. Fl. *pl. 92.* 1825.—*Piper maculosum* L., Sp. Pl. 30. 1753.—*Peperomia septuplinervia* C.DC., Jour. Botany 4:142. 1866.—*Peperomia monsterifolia* Grisebach, Cat. Pl. Cub. 64. 1866.—Ascending, sparingly hairy, succulent, the rather thick stem mottled; leaves alternate, elliptic-ovate, subcuspidate, peltate near the rounded or truncately subcordate base, 8–11×12–17 cm., the mottled petiole 6–15 cm. long; spikes solitary or paired at the end, large (6×250 mm.), caudately tapering; berries subsessile, ovoid, tapering into an equilong beak; stigma anterior on the beak.

Through the Antilles, the type from Haiti (*Plumier*).

PEPEROMIA VARIEGATA Ruiz and Pavon, Fl. Peru. 1:33. *pl. 52.* 1794.—Aspect of and not considered by MIQUEL separable from the preceding, but glabrous and with broader leaves 12–15 cm. long.

Peru to Demarara, and reported for Costa Rica and Guatemala possibly on forms of the preceding; the type from Peru.

UNIVERSITY OF ILLINOIS
URBANA, ILL.

## EXPLANATION OF PLATES I–IV

Habit illustrations are of natural size; inflorescence or fruit details are enlarged 20 diameters.

*PLATE I*

FIG. 1.—*Peperomia schizandra*, from type.

FIG. 2.—*Peperomia schizostachya*, from type.

FIG. 3.—*Peperomia mexicana*, from type number, also cotype of *Piper parvulum*.

FIG. 4.—*Peperomia astyla*, from type.

FIG. 5.—*Peperomia Painteri*, from type.

FIG. 6.—*Peperomia gracillima*, from cotype.

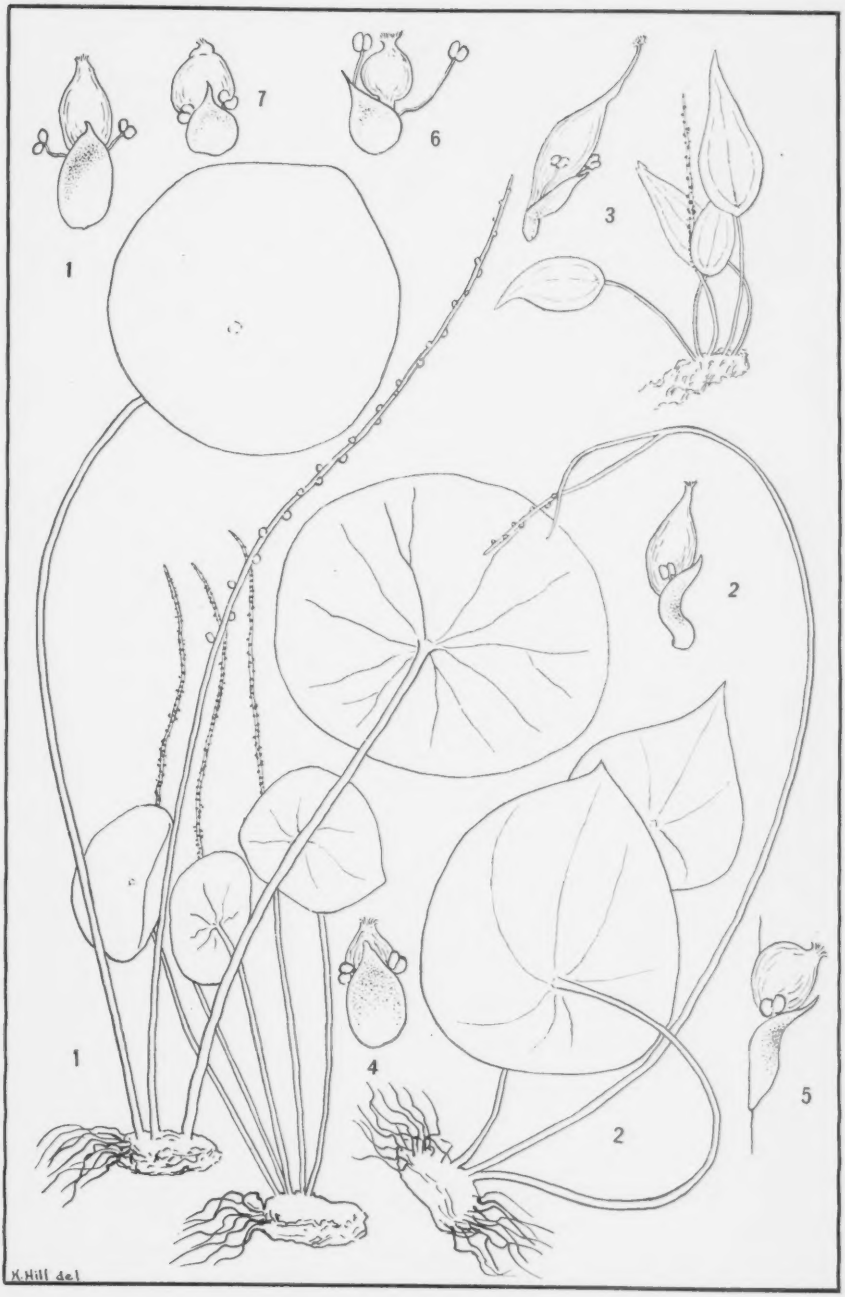
FIG. 7.—*Peperomia Parryana*, from type.

*PLATE II*

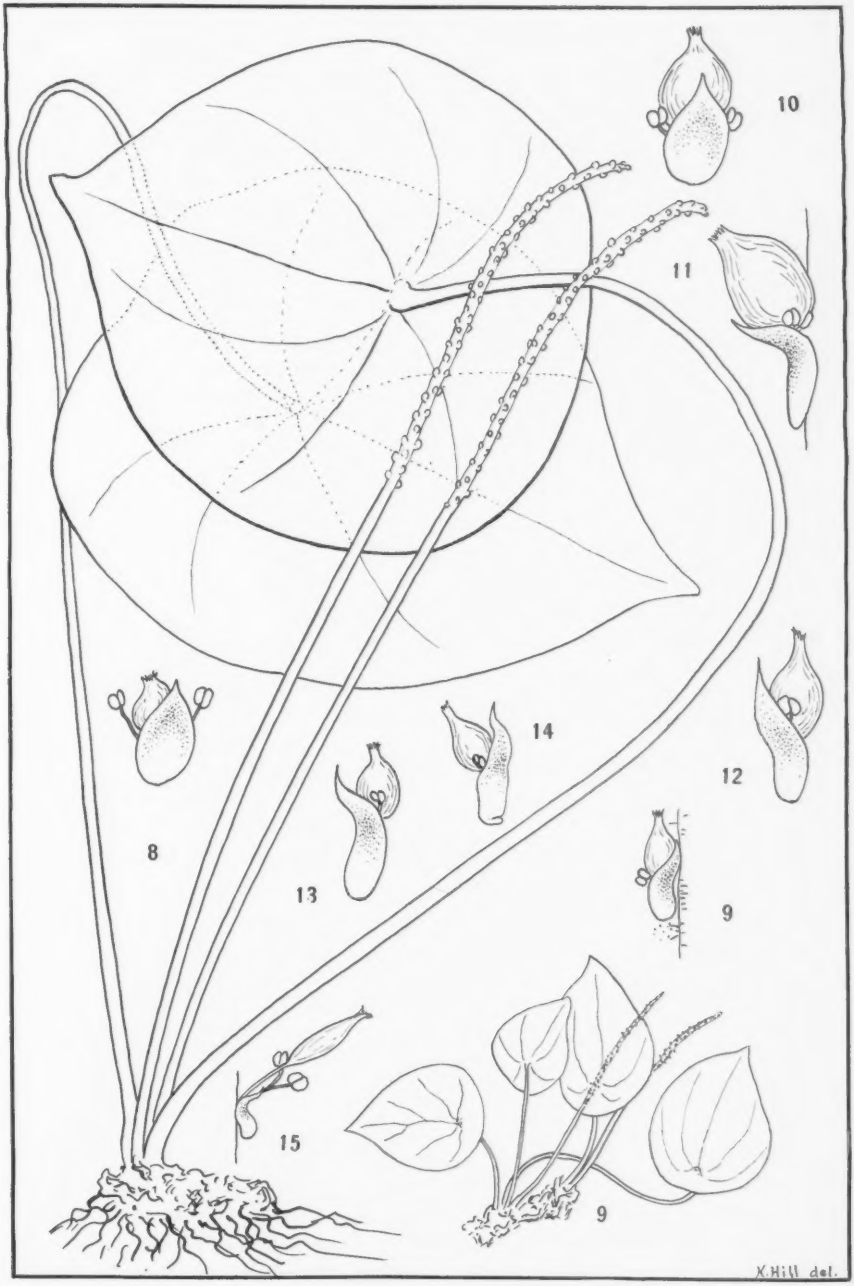
FIG. 8.—*Peperomia macrandra ampla*, from type.

FIG. 9.—*Peperomia Tuerckheimii*, from type collection.

FIG. 10.—*Peperomia campylotropa*, from sheet in United States National Herbarium (?erroneously) as *Bourgeau* 3020.

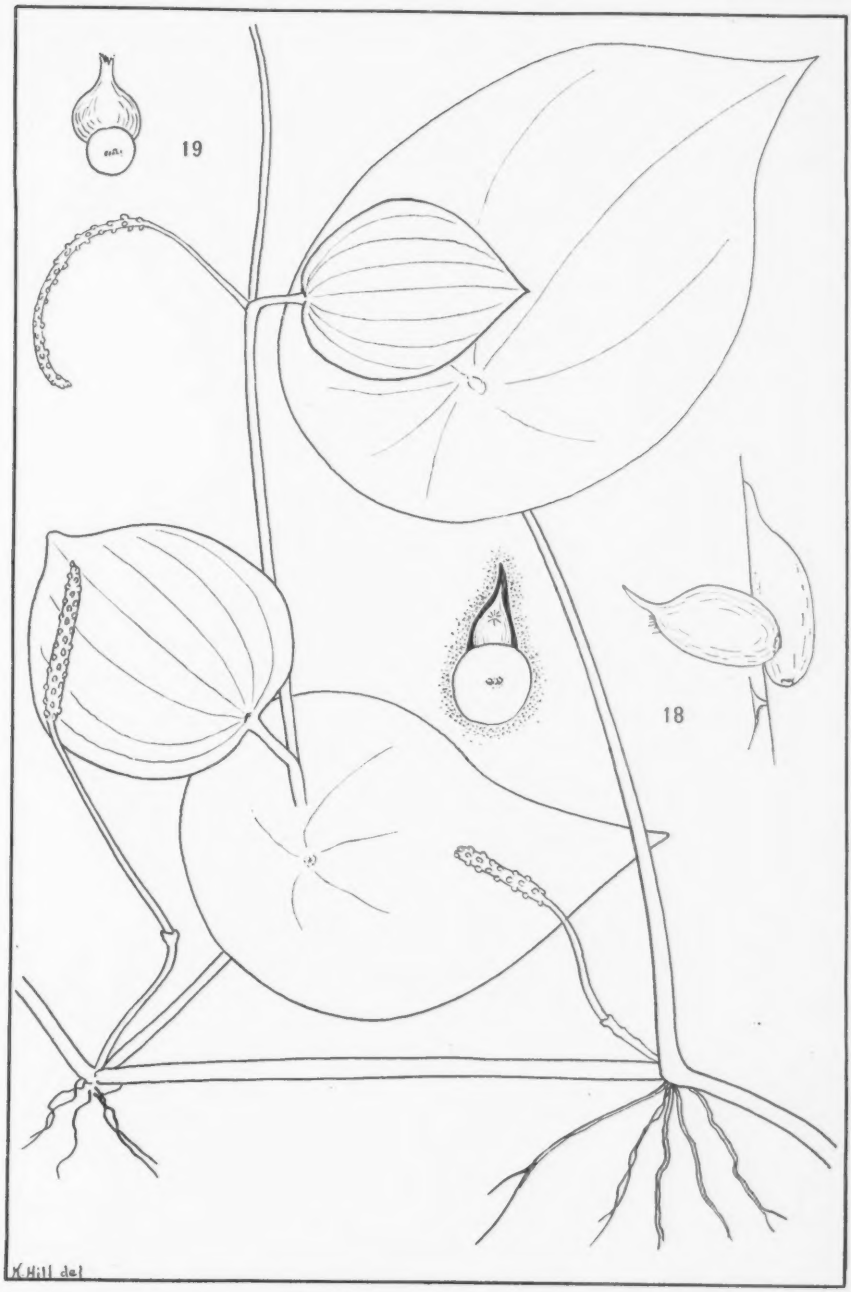



TRELEASE on PEPEROMIA




TRELEASE on PEPEROMIA

TRELEASE on PEPEROMIA




TRELEASE on PEPEROMIA

FIG. 11.—*Peperomia amphoricarpa*, from type.

FIG. 12.—*Peperomia tenuimucronata*, from type collection.

FIG. 13.—*P. claytonioides longiscapa*, from a Santa Rosa specimen (*von Tuerckheim* II, 2319).

FIG. 14.—*Peperomia sciaphila*, from type collection.

FIG. 15.—*Peperomia peltata*, from type collection.

*PLATE III*

FIG. 16.—*Peperomia tecticola muricola*, from type.

FIG. 17.—*Peperomia puberula*, from Santa Rosa specimen (*Heyde* and *Lux* 3826).

*PLATE IV*

FIG. 18.—*Peperomia hernandifolia:* habit of var. *filipes*, from type; fruit of insular form, from Dominica (*Eggers*).

FIG. 19.—*Peperomia cordulatiformis*, from type.

# FLOWERS AND INSECTS. XXI

## DATA OF ANTHECOLOGY

CHARLES ROBERTSON

In KNUTH'S *Blütenbiologie* is found a mixture of the botanical subject of insect visitors of flowers, the entomological subject of flower visits of insects, and collectors' notes which have no definite relation to either subject but rather to the personal movements of collectors. He states that his work is based upon MÜLLER'S, but he fails to include data from works which follow MÜLLER'S method (MÜLLER'S *Alpenblumen* and MACLEOD'S works on flowers of the Pyrenees and Flanders), and includes collectors' notes which suppress it, although such notes from French and Italian records are excluded as perhaps not justifying the labor of compilation. In a work which repeats MÜLLER'S lists for Low Germany for the third time American anthecological lists are suppressed.

ANTHECOLOGICAL DATA.—These are lists of insect visitors made to show the species, their frequency, their efficiency as pollinators, and the possibility of their having some influence in determining the characters of the flowers. MÜLLER'S lists show these details. In the case of the bees he indicated the sexes, and whether they were sucking nectar or collecting pollen. To note the sexes is important because female bees fly longer than males and are more likely to make repeated visits. To note the fact of pollen-collecting is also important. A female bee will carry pollen all day from flowers on which the male rarely occurs. From observations at Carlinville the females of nest-making bees average 20.6 visits to the males 10.3. The inquiline bees show females 8.8 to males 8.0. In anthecology MÜLLER'S lists are valuable as regards species and visits, but they fail to indicate the frequency. In 1908 I rejected MÜLLER'S method and adopted the practice of capturing the visitors as they came, noting species, and counting individuals. It is impossible to indicate the importance of insects to flowers by lists of species, because efforts to increase the lists involve an exaggeration of the importance of rare and exceptional cases.

ENTOMOLOGICAL DATA.—If lists of visitors of flowers are broken up and the visits are redistributed under each insect, the subject changes from a botanical to an entomological one. It would require as much space and as many entries to make the second set of lists. If these insect visits are distributed under the different flower classes and colors, they may still hold an indirect relation to anthecology. To be correctly arranged as entomological data

TABLE I

| Data | Lists | Bees | Diptera | Other Hymenoptera | Lepidoptera | Coleoptera, Hemiptera | Total |
|---|---|---|---|---|---|---|---|
| 1. First 62 | | | | | | | |
| Entomological | 122 | 82.5 | 4.2 | 6.3 | 4.6 | 2.3 | 476 |
| Anthecological | 175 | 33.3 | 41.8 | 4.8 | 10.1 | 9.7 | 1647 |
| Next 38 | | | | | | | |
| Entomological | 108 | 90.5 | 1.4 | 2.1 | 4.8 | 1.0 | 475 |
| Anthecological | 141 | 60.6 | 9.5 | 1.6 | 25.6 | 2.5 | 1077 |
| Total 100 | | | | | | | |
| Entomological | 230 | 86.5 | 2.8 | 4.2 | 4.7 | 1.6 | 951 |
| Anthecological | 316 | 44.1 | 29.1 | 3.5 | 16.2 | 6.8 | 2724 |
| 2. 65 Compositae | | | | | | | |
| Entomological | 213 | 79.2 | 10.2 | 5.8 | 3.0 | 1.5 | 985 |
| Anthecological | 255 | 35.6 | 37.0 | 5.1 | 14.7 | 7.3 | 3309 |
| 59, Germany, Müller | ..... | 48.1 | 27.1 | 7.7 | 9.8 | 7.0 | 1103 |
| 85, Illinois | ..... | 40.3 | 27.1 | 16.9 | 11.2 | 4.4 | 4030 |
| 3. 51 plants | | | | | | | |
| Flowers and insects | ..... | 40.4 | 25.1 | 15.5 | 13.8 | 4.9 | 1386 |
| Anthecological, Europe | ..... | 42.5 | 34.7 | 6.3 | 8.9 | 7.5 | 887 |
| Entomological, Europe | ..... | 88.6 | 4.2 | 2.3 | 1.5 | 3.1 | 256 |
| 4. Visits in Knuth | ..... | 44.6 | 25.4 | 12.4 | 11.7 | 5.7 | 6127 |
| Other observers | ..... | 53.2 | 17.8 | 11.0 | 10.6 | 7.2 | 3289 |
| Flowers and insects | ..... | 43.4 | 26.5 | 12.2 | 12.3 | 5.3 | 6163 |

they should be distributed under the natural families of plants. The visits of each nest-making bee should be distributed under three headings: one showing the pollen visits of the female, another showing the nectar visits of the female, and a third showing the nectar visits of the male. If they are arranged under alphabetical lists of plants, and the sexes and pollen and nectar visits of the bees suppressed, they have little use as entomological data.

MIXING ANTHECOLOGICAL LISTS AND COLLECTORS' NOTES.—In his *Blütenbiologie* KNUTH gives a list of 37 entomologists whose notes are included as if they furnished anthecological data. The

difference is quite definitely shown in the first 100 cases in which collectors' notes and anthecological lists are given for the same flowers (table I, 1). The latter show for visits: bees 44.1 per cent and flies 29.1, while the former show bees 86.5 per cent and flies 2.8. One indicates a rather miscellaneous assemblage, while the other shows such a strong preponderance of bees as to reveal the fact that most of the entomologists were collecting bees particularly. In the first 62 cases the bee visits stand 82.5 per cent, flies 4.2, against bees 33.3, flies 41.8, the maximum changing from bees to flies. In the next 38 cases the bee visits are 90.5 and 60.6, a difference of 29.9. These are Papilionaceae and rather melittophilous, so that the bee collectors' notes give a more correct approximation. In many cases they did not say whether the bees were collecting pollen or not, and often did not mention the sexes at all.

In the case of 65 species of Compositae for which there were both collectors' notes and anthecological lists (table I, 2) the percentages of visits stand: for the former, bees 79.2, flies 10.2; for the latter, bees 35.6, flies 37.0, the maximum again shifting from bees to flies. Comparing 59 species observed by MÜLLER (*Fertilisation of flowers*), 65 observed by anthecologists in Europe, and 85 observed by me in Illinois, there is more resemblance between the European and Illinois lists than between collectors' notes and anthecological lists based on the same 65 species observed in Europe.

In the case of 51 plants observed both in Europe and Illinois (table I, 3) the percentages of bee visits show: for the collectors 88.6, for the anthecologists, Europe 42.5, Illinois 40.4. Here again there is more resemblance between anthecological observations for Europe and Illinois than between anthecological lists and collectors' notes for Europe. As entomological data the collectors' notes are just as unsatisfactory. In the three cases the percentages of visits of flies range: for the collectors, 1.4 to 10.2, with an average of 4.5; for the anthecologists, 9.5 to 41.8, with an average of 29.5.

The insect visits to flowers recorded in my *Flowers and insects* are not included in KNUTH'S work, but are broken up in a final list and redistributed under the insects, making a quasi-entomological subject of them, but they are vitiated by being mixed with collectors' notes. These visits recorded in KNUTH (table I, 4) show for bees 44.6 per cent of the total. The visits recorded for other

observers show bees as 53.2 per cent. This is a higher percentage than is shown in anthecological observations of any region, and indicates that observations were introduced which discriminated in favor of bees to the exclusion of other insects. My *Flowers and insects* shows for bee visits 43.4 per cent instead of 44.6. The difference comes from using some entomological notes which were separated from my anthecological lists and were never intended to be used as anthecological data.

DYSTROPIC VISITS.—Useless visits of insects should be considered from the standpoint of the flowers and regarded as marks of imperfect adaptation. LOEW has called insects which make such visits "dystropic," and MÜLLER has called *Bombus mastrucatus* a "dysteleologue," as if these insects were under some teleological obligation to make useful visits. So far as the flower is concerned, a bee collecting pollen from it without effecting pollination cannot count among the useful visitors. So far as the bee is concerned, however, the visit is legitimate and the flower must be counted among its pollen visits. In the case of a family of small bees (Halictidae) 165 visits, mostly for pollen, were observed to flowers which they failed to pollinate. KNUTH, while omitting American visits under the plants to which they relate and redistributing them under the insects which make them, has indicated the so-called dystropic visits under conditions which make them entomologically irrelevant.

EXAGGERATION OF FRAGMENTARY OBSERVATIONS.—Probably anyone who contemplates methods of publication will notice this as a common characteristic. Fragmentary observations, as regards publication, reviewing, or abstracting, get more consideration than they are entitled to, for the reason that it is easier and cheaper to do so. When it was complained that KNUTH suppressed anthecological lists, the statement did not apply to the most fragmentary, the most worthless ones. His work gives 55 of my lists averaging 2.8 visits, and excludes 207 lists averaging 28.9 visits. There is only one reason: the short lists are easier to copy and to print.

One list containing 18 Syrphidae and 128 other insects is omitted, while another list for the same plant, consisting exclusively of 5 Syrphidae, is given. Special mention is made of the occurrence

of one Syrphid on a flower of which a list containing 10 Syrphidae and 21 other insects is not included. In *Blütenbiologie* **2**:254, KNUTH specially mentions the hive-bee and *Syritta pipiens* as visitors of *Ptelea trifoliata*, but in **3**:444 a list containing these two insects together with 49 others is merely grouped. In **2**:476, *Andrena combinata* (sex?), observed by SCHMIEDEKNECHT, is specially mentioned, while MACLEOD'S list containing 6 bees (sexes given) and 70 other insects is combined. In the third volume of *Blütenbiologie* the seeming discrimination in favor of collectors' notes as against anthecological lists perhaps may be explained partly from the fact that they are usually short. Why long lists are usually published in the second volume and always omitted in the third requires another explanation.

GENERAL RESULTS.—While one might hold that a general work should treat all of the data alike, and that, when it repeats one set of lists for the third time, it should collect another set once, it is not certain that it should give local lists at all. As regards details, local lists decline in value as the distance increases from the place where they were made. As regards species, the lists from Illinois and Germany are quite different. A student in one place does not need to know the specific name of every insect taken on flowers in the other, but only the different kinds. Of course in giving the general groups errors may easily be made. "Hymenoptera" is used for the three groups, long-tongued bees, short-tongued bees, and other Hymenoptera, for any two of them, or for any one of them exclusively. Bees and the other Hymenoptera do not belong to the same ecological class. Of 437 entomophilous flowers bees were found on 95.4 per cent, while flies were found on 60.4 per cent, and the other Hymenoptera on only 43.0 per cent. Table I shows that the visits of bees range from 33.3 to 60.6 per cent, while the visits of other Hymenoptera range from 1.6 to 16.9. In DAVIS' *Handbook of flower pollination* (**1**:165), "hymenopterid flowers" is a translation of "Immenblumen," used by KNUTH in referring to a statement in which LOEW wrote "Bienenblumen."

CARLINVILLE, ILL.

# CURRENT LITERATURE

## BOOK REVIEWS

### Soil conditions and plant growth

The rapid advancement of our knowledge of the soil as related to plant production is reflected by the necessity for a new revision of RUSSELL's *Soil conditions and plant growth*.[1] The fourth edition appears in a slightly different size and binding, marking its separation from the series of *Monographs on Biochemistry* edited by PLIMMER and HOPKINS, and the inauguration of a new series, *The Rothamsted Monographs on Agricultural Science*, edited by E. J. RUSSELL. Students of soil problems and plant physiology will welcome this departure, and await with keen interest the other five volumes announced as in preparation.

The present volume covers the entire field, and the others are to deal with more restricted phases, in more complete and more critical fashion than would be possible without undue expansion of the original work. The chapter headings remain about as they were. Chapter ii becomes "Soil conditions affecting plant growth" instead of "The requirements of plants"; and a second appendix is added, which shows in tabular form the amounts of minerals absorbed from the soil by agricultural crops in England.

Nearly every chapter shows enlargement, especially those which deal with the soil conditions affecting plant growth, the biological conditions of the soil, and the relation between the microorganic population of the soil and plant growth. The literature citations are increased from 18 to 28 pages, and the whole work from 240 to 355 pages of text. More figures have been added, with a frontispiece of BOUSSINGAULT, the founder of modern agricultural chemistry, which adds to the attractiveness of the volume.

The literature mentioned by WALSTER[2] in the review of the third edition has nearly all been given consideration in the revision, and the discussion is brought up to date as nearly as possible. The book is an excellent general introduction to the field, and will be indispensable to students of plant physiology, ecology, and agriculture. With this new departure in publication of monographs, the Rothamsted Station, already justly famous for its splendid contributions to agricultural practice, is certain to extend very greatly its influence as a center of scientific investigation.—C. A. SHULL.

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[1] RUSSELL, E. J., Soil conditions and plant growth. 4th ed. pp. xii+406. *figs. 32*. New York: Longmans Green & Co. 1921.

[2] BOT. GAZ. **67**:171–173. 1919.

## NOTES FOR STUDENTS

**Species hybrids.**—According to one definition of species, which maintains that crossing is impossible beyond the species boundary, there can be no such thing as a species hybrid. The experience of many breeders, however, shows numerous cases of successful crossing between forms that are commonly regarded as distinct species. As might well be expected, many of these species crosses exhibit peculiarities, and it is of considerable theoretical interest to analyze them. In this connection it is enlightening to consider some of the ideas which were suggested to EAST and HAYES[3] by their experiments on hybrid vigor, and which may be freely interpreted as follows. As the width of a cross increases, four characteristic stages are encountered. (1) Very narrow crosses commonly bring little more than the redistribution of a few Mendelian characters. (2) Wider crosses, involving a considerable number of Mendelian factors, in many plants will produce a first hybrid generation which is characterized by a certain amount of hybrid vigor, the amount increasing with the width of the cross. (3) A point is reached where the fertility of the hybrid falls off, and at a certain width of cross perfectly sterile hybrids may be expected. It is interesting that hybrid vigor commonly continues to increase even though fertility decreases. Here loss in "efficiency" in the reproductive system is distinctly not accompanied by loss in efficiency in vegetative development. This peculiarity is clarified by the following idea. Wide crosses involve the fusion of relatively "inharmonious" gametes, which might be expected to produce disturbances in the ontogeny of the resulting individual. The grosser mechanism which regulates vegetative development can evidently weather such disturbances, while the more finely balanced mechanism of gamete formation is upset. (4) Finally, in the widest crosses, even vegetative development is impaired, and poorly developed hybrids result, a point eventually being reached where crosses are entirely unsuccesful.

Species crosses in *Nicotiana*, made by GOODSPEED and CLAUSEN,[4] and by EAST,[5] and the wheat-rye crosses of JESENKO[6] gave results which, although not identical, were significantly similar. All seem to be of the third type, the first generation hybrids being vigorous but almost sterile. The nature of this sterility is pictured in the following theory, which was proposed by BABCOCK and CLAUSEN, and supported and somewhat enlarged by EAST. Two *Nicotiana* species, *A* and *B*, each having a haploid chromosome number of 24, are crossed

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[3] EAST, E. M., and HAYES, H. K., Heterozygosis in evolution and in plant breeding. U.S. Dept. Agric. Bur. Plant Ind. Bull. 243. pp. 58. 1912.

[4] GOODSPEED, T. H., and CLAUSEN, R. E., Mendelian factor differences versus reaction-system contrasts in heredity. Amer. Nat. **51**:31–46, 92–101. 1916.

[5] EAST, E. M., A study of partial sterility in certain hybrids. Genetics **6**:311–365. *figs.* 17. 1921.

[6] See BABCOCK, E. B., and CLAUSEN, R. E., Genetics in relation to agriculture New York. 1918 (p. 238).

to produce a hybrid which contains 24 chromosomes from parent *A* and 24 from parent *B*. Reduction division by this hybrid should produce gametes of numerous types, ranging from those which would possess the 24 chromosomes of the *A* parent and none of the *B* chromosomes, to the other extreme in which the reverse would be true. It is assumed that gametes in the intermediate condition, with a liberal mixture of *A* and *B* chromosomes, fail to develop. "Any gamete containing elements derived from both systems would give a reaction system subject to profound disturbances incident upon the inharmonious relations set up" between the *A* and *B* elements. In consequence the only gametes which successfully develop are such as contain all or almost all of the *A* chromosomes, or all or almost all of the *B* chromosomes. This hypothesis of selective survival of the gametes produced by the $F_1$ species hybrid is supported by the following very striking facts. Back crosses with either parent result in the production of a relatively much higher number of forms identical or almost identical with that parent than would otherwise be expected. Also, in the scanty $F_2$ generation which it is sometimes possible to obtain, many more individuals appear which are identical or almost identical with the original grandparents (*A* and *B*) than would otherwise be expected.

SAX[7] arranges the species of *Triticum* in three groups, characterized by haploid chromosome numbers of 7, 14, and 21 respectively. Crossing within the groups produces fertile hybrids, but crossing between the groups results in more or less sterile hybrids. It is noteworthy that the $F_1$ endosperms are well developed in the fertile crosses, but shriveled in those crosses which are to produce sterile or partially sterile $F_1$ plants. In all cases, however, hybrid vigor appears in the vegetative parts of the $F_1$ plants. Evidently endosperm development as well as gametogenesis is sensitive to the disturbances resulting from the union of "inharmonious" gametes. The $F_2$ results of SAX,[8] however, appear not to agree with the ideas of the other investigators, since in this generation no greater sterility appears in the intermediates than in the segregates resembling the grandparents. Ecologists as well as geneticists will be interested in the natural law which is suggested by this work of SAX. In a group of species of which the chromosome numbers vary in multiples of an original basic number, adaptability varies directly with the chromosome count. Thus the 21 chromosome wheats are the most adaptable, and the 7 chromosome wheats are the least adaptable.—M. C. COULTER.

**Fusarium resistant cabbage.**—The selection of *Fusarium* resistant strains of cabbage is being continued at the Wisconsin Experiment Station by JONES[9]

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[7] SAX, KARL, Sterility in wheat hybrids. I. Sterility relationships and endosperm development. Genetics **6**:399–416. 1921.

[8] SAX, KARL, Chromosome relations in wheat. Science **54**:413–415. 1921.

[9] JONES, L. R., WALKER, J. C., and TISDALE, W. B., *Fusarium* resistant cabbage. Wis. Agric. Exp. Sta. Res. Bull. 48. 1–34. *figs.* 10. 1920.

and others. In an earlier report[10] the symptoms of the yellows disease of cabbage are described. It is caused by a vascular parasite (*Fusarium conglutinans*) which persists indefinitely in the soil, eventually forcing abandonment of large areas of fertile soil for cabbage culture. Soil disinfection having proved ineffective or impracticable, the only hope for control lies in the selection of disease resistant strains. Selections have been continued since 1910 with very effective results.

The success of this work rests largely on the fact that the cabbage is nearly self-sterile and is normally cross-pollinated. As a result all standard varieties of cabbage are variable in type to a greater or less degree. Fortunately, moreover, wherever cabbage was grown on soil badly infested with yellows, although a large majority of the plants were killed, always a few showed a high degree of resistance and developed normally. By selection of such heads for seed growing the next season, and saving the seed from each plant separately, individual head strains were secured which were planted on badly infected soil the second season. Thus by continual selection and elimination of weaklings, high resistant strains were quite readily secured.

It should be pointed out that there are numerous horticultural varieties of cabbage adapted to various localities and uses. In making selections for resistance, therefore, the importance of adhering as strictly as possible to the horticultural characteristics of the original type was recognized. Consequently the earlier efforts were directed upon the late or winter type of cabbage, known as Hollander or Danish Ball Head, which is grown most generally in Wisconsin. A highly resistant strain of this variety was secured to which the name Wisconsin Hollander has been given. The latter differs slightly from the original in having a more vigorous plant with a longer stem and flatter head, and in maturing somewhat later. These objectionable features have now been overcome by reselecting from the Wisconsin Hollander an earlier strain with the more desirable qualities of shorter stem and spherical head. For purposes of distinction the former strain is now designated as Late Wisconsin Hollander and the latter as Early Wisconsin Hollander.

Following similar methods, selections from two late summer varieties of the flat head type, the All Seasons and the Brunswick, have yielded highly resistant strains of each. These new strains are known as the Wisconsin All Seasons and Wisconsin Brunswick. To meet further demands of the trade, selections are now under way on three still earlier maturing varieties, the All Head Early, the Glory of Enkhuizen, and the Copenhagen Market.

In general, throughout this work, a number of closely similar seed heads from the same source were grown in mixed plantation to insure sufficient setting of seed. The seed from individual plants was then saved separately and tried out in head to row tests. In certain cases, however, attention was

[10] JONES, L. R., and GILMAN, J. C., The control of cabbage yellows through disease resistance. Wis. Agric. Exp. Sta. Res. Bull. 38. 1–70. *figs.* 23. 1915.

given to selfing of individual plants with some success. In order to hasten the work, winter seed growing in the greenhouse or out-of-doors in the southern states was practiced with moderate success.

Seedsmen and growers are interested in the possibility of producing seed of these resistant strains in the commercial cabbage seed growing sections. The difficulty encountered in this procedure lies in the fact that yellows does not occur generally in our seed growing sections. The small percentage of susceptible plants would thus not be eliminated, and tendency toward reversion would be expected. The investigators have studied this question by having a resistant strain grown for one generation in the Puget Sound seed growing section, and then testing it on diseased soil together with Wisconsin grown strains. Little or no reversion was noted when this was carried on for only one generation. The practice, therefore, is being approved for the present provided precautions are taken to supply stock seed each year from plants selected on diseased soil, and to so isolate seed fields as to avoid all possibility of cross-pollination with other varieties.—J. C. WALKER.

**Abnormal behavior in corn endosperm.**—If pollen from red grained corn be applied to the silks of a colorless grained variety, the resulting grains will be red. This familiar phenomenon of xenia is explained by the known facts of double fertilization. This cross, however, may produce a very few aberrant grains; of these, only a part of the surface is red and the rest colorless. Such grains are commonly spoken of as "mosaics," while the terms "mottled," "spotted," and "variegated" usually refer to different phenomena. WEBBER[11] observed this phenomenon, and suggested two possible explanations: (1) the second male nucleus fails to fuse with the female fusion nucleus, and these two elements divide independently in producing endosperm; (2) the second male nucleus fuses with one of the female polars, the other polar dividing independently in the production of endosperm.

The first explanation was disproved by EAST[12] in the following manner. Factors *R* and *C* must be present simultaneously for the production of red endosperm. A cross between the two colorless grained types, *CCrr* and *ccRR*, therefore, will produce a red grained ear. Even here, however, aberrant grains sometimes appear, part of the grain being white and the rest colorless. Failure of the second male nucleus to fuse with the female polar nucleus in such a case would result in a grain which was entirely colorless, a thing which never occurred. It is only by fusion of male and female nuclei that any part of the endosperm can be red.

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[11] WEBBER, H. J., Xenia, or the immediate effect of pollen in maize. U.S. Dept. Agric., Div. Veg. Phys. Path. Bull. **22**:1–44. 1900.

[12] EAST, E. M., Xenia and the endosperm of angiosperms. BOT. GAZ. **56**:217–224. 1913.

WEBBER's second explanation was disproved by EMERSON[13] as follows. A colorless, sugary type, *CCrrsusu*, was used as female parent in a cross with a colorless, starchy type, *ccRRSuSu*. The resulting grains were red, starchy, save for a few aberrant grains which were red in part and colorless in part but starchy throughout. WEBBER's second explanation fails here, since fusion of the second male nucleus with only one of the polars would produce grains which were red, starchy in part (from male nucleus fused with one polar) and colorless sweet in part (from independent polar).

These two critical experiments serve to disprove WEBBER's explanations and demonstrate that the normal program of double fertilization is invariable in corn. The next thing which was invoked to explain these aberrant grains was "somatic mutation" in the endosperm, but for several reasons this was unsatisfactory as an explanation.

EMERSON[14] has finally obtained critical evidence which indicates a very satisfactory explanation of the phenomenon. The factor *wx* for waxy endosperm (*Wx*, corneous endosperm) is known to be carried on the same chromosome with the *C* factor. A cross was made between a colorless, waxy female parent, *c-wx c-wx* and a red corneous male parent, *C-Wx C-Wx* (the *R* factor being present in both parents). The resulting triploid endosperm was of the formula *c-wx C-wx C-Wx*. If non-disjunction (passing of both halves of a divided chromosome to one pole) occurred in connection with the third of these chromosomes, one of the resulting nuclei would be diploid for this chromosome set. *c-wx c-wx*, and the other tetraploid, *c-wx c-wx C-Wx C-Wx*. Endosperm produced by the former should be colorless, waxy; endosperm produced by the latter should be red, corneous. Emerson obtained aberrant grains which were of exactly this constitution, the colorless areas being at the same time waxy, and the red areas corneous. This experiment, considered together with the previous ones, indicates that occasional non-disjunction is the explanation of these aberrant grains. The frequency of these particular aberrant grains is one in 423, and one may expect non-disjunction to take place in connection with some one chromosome in the corn endosperm in about one of every fourteen grains. Direct cytological demonstration is to be hoped for. Non-disjunction is known to occur at times elsewhere in the plant and animal kingdoms. Possibly the triploid nature of endosperm furnishes an especially favorable condition for its occurrence.—M. C. COULTER.

**Prairie vegetation.**—The prairies of Illinois, occurring as they do on the tension line between great forest and and grassland formations of North America, afford peculiar advantages in the study of the development of this

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[13] EMERSON, R. A., Anomalous endosperm development and the phenomenon of bud sports. Zeit. Induk. Abstamm. Vererb. **14**:241–259. 1915.

[14] EMERSON, R. A., Genetic evidence of aberrant chromosome behavior in maize endosperm. Amer. Jour. Bot. **8**:411–424. *fig.* 1. 1921.

type of vegetation. In a recent article SAMPSON[15] has made an excellent contribution to our knowledge of these rapidly disappearing grasslands. He found, in various parts of the state, remnants of the original prairie grasslands varying in size from strips along roadways and railways to tracts of hundreds or even thousands of acres in extent. Some of the largest areas were on the floodplain of the Mississippi River and occur even within the city limits of Chicago. The principal virgin areas were visited during the summers of 1915–18 and carefully studied.

The most notable contribution appears in a very complete explanation of the dynamics of these grasslands. Two main lines of succession are recognized, the hydrarch and xerarch, with a common climax association type in which *Andropogon furcatus* is dominant. The hydrarch succession commonly begins with an association dominated by *Scirpus fluviatilis*, succeeded by others in which *Spartina Michauxiana* or *Calamagrostis canadensis* is abundant. In the subclimax *Panicum virgatum* or *Agrostis alba* may be most conspicuous. Variations in the intermediate stages occur and are illustrated by examples.

Owing to the agricultural value of the upland prairie areas the xerarch succession is not so easily solved, although there is abundant evidence of the nature of the climax association. Mixtures of herbaceous species with few grasses seem to be the probable pioneer forms, with a mixed aggregation of grasses or a comparatively pure stand of *Andropogon scoparius* as the intermediate stage.

The present abundance of *Poa*, appearing both as the dominance of *P. pratensis* in the climax association and of *P. compressa* in the subclimax of the xerarch succession, is shown to be due to man's influence in cutting and grazing. The retrogressions due to grazing, as well as the various types of succession, are made clear by numerous diagrams, by floristic analyses of the various associations, and by an annotated list of the principal species.

A very commendable feature of the report is a non-technical summary in which the main results of the study, including the principal successions, are stated in terms intelligible to the ordinary citizen acquainted with the prairies but without botanical training. A series of excellent plates also add to the interest and value of the report.—G. D. FULLER.

**Taxonomic notes.**—The collection of plants made by COMPTON in New Caledonia and the Isle of Pines in 1914 is being published by various taxonomists, the first part containing the Angiosperms by RENDLE, BAKER, and MOORE.[16] It includes 830 species, 230 of which are new. The ten new genera

[15] SAMPSON, H. C., An ecological survey of the prairie vegetation of Illinois. Ill. Dept. Regist. and Educ. Div. Nat. Hist. Surv. Bull. **13**:523–577. *pls. 48–77. figs. 9.* 1921.

[16] A systematic account of the plants collected in New Caledonia and the Isle of Pines by Professor R. H. COMPTON in 1914. Part I. Flowering plants (Angiosperms), by RENDLE, A. B., BAKER, E. G., and MOORE, S. LEM. Jour. Linn. Soc. **45**:245–417. *pls. 13–24.* 1921.

are as follows: *Comptonella* (Rutaceae), *Salaciopsis* (Celastrineae), *Montagueia* (Anacardiaceae), *Paracryphia* (Eucryphiaceae), *Enochoria* (Araliaceae), *Merismostigma* (Rubiaceae), *Tropalanthe* (Sapotaceae), *Depanthus* (Gesneraceae), *Adenodaphne* (Lauraceae), and *Dendrophyllanthus* (Euphorbiaceae). The largest families are Orchidaceae (60 spp.), Euphorbiaceae (60 spp.), Rubiaceae (60 spp.), and Myrtaceae (56 spp.), and they also furnish a large proportion of the novelties described.

LESTER-GARLAND[17] has published a revision of the African genus *Baphia* (Leguminosae), recognizing 58 species, 3 of which are described as new. As an illustration of the recent development of our knowledge of the African flora, it may be stated that this genus is represented by 6 species in the *Genera Plantarum*.

BLATTER and HALL[18] have published a new genus (*Bonnayodes*) of Scrophulariaceae from India, related to *Bonnaya*, *Ilysanthus*, and *Limnophila*, but differing from each in a decisive character.

MOORE[19] has described a new genus (*Phanerocalyx*) of Oleaceae from Africa. It is represented by two species, and is most nearly related to *Strombosia*.

HUTCHINSON and PEARCE[20] have published a revision of the African genus *Tryphostemma* (Passifloraceae), recognizing 25 species, 6 of which are described as new. In the second volume of the *Flora of Tropical Africa* the genus was represented by a single species.

SPRAGUE[21] has published a revision of *Belotia*, a Central American genus of Tiliaceae, recognizing 11 species, 6 of which are described as new.

GLEASON[22] has presented a much needed rearrangement of the Bolivian species of *Centropogon* and *Siphocampylus* (Lobeliaceae), genera which have been very much confused, recognizing 14 species of the former genus and 26 of the latter.

WAINIO[23] has published two papers describing a collection of Japanese lichens by YASUDA. Thus far the published list includes 182 species, 94 of which are described as new.—J. M. C.

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[17] LESTER-GARLAND, L. V., A revision of the genus *Baphia* DC. (Leguminosae). Jour. Linn. Soc. **45**:221–243. 1921.

[18] Species novae Indiae orientalis. Decas I. Jour. Indian Bot. **2**1:44–54. 1921.

[19] MOORE, S. LEM., *Alabastra diversa*. XXXIV. Jour. Botany **59**:244–249. 1921.

[20] HUTCHINSON, J., and PEARCE, K., Revision of the genus *Tryphostemma*. Kew Bull. no. 7. 257–266. 1921.

[21] SPRAGUE, T. A., A revision of the genus *Belotia*. Kew Bull. no. 7. 270–278. 1921.

[22] GLEASON, H. A., A rearrangement of the Bolivian species of *Centropogon* and *Siphocampylus*. Bull. Torr. Bot. Club **48**:189–201. 1921.

[23] WAINIO, E. A., Lichens ab A. YASUDA in Japonia collecti. Bot. Mag. Tokyo **35**:45–62; 63–80. 1921.

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